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National Hydrology Research Institute
Institut national de recherche en hydrologie

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Saskatoon, Saskatchewan
S7N 3H5

MONITORING AND PREDICTIVE CAPABILITY FOR EVALUATING IMPACTS FROM IN-SITU OIL SAND/HEAVY OIL SUBSURFACE DISPOSAL PRACTICES

NHRI Contribution No.90025

1990

MANAGEMENT PERSPECTIVE

Starting in 1983 Environment Canada let a series of contracts to Alberta Research Council (ARC) to better:

i) define the geological and hydrological constraints on subsurface fluid injection;

ii) characterize wastewaters currently being injected at in-situ oil sands/heavy oil plants in Alberta; and

iii) investigate phenol partitioning in the laboratory to simulate waste fluid-reservoir rock interactions.

These studies were coordinated with the Alberta Department of the Environment's hydrogeological modeling work for the Cold Lake area which was also carried out by ARC.

Recognizing the need to verify theoretical and laboratory studies the feasibility and cost were ascertained for a field program to monitor impacts resulting from waste fluid injection in deep sedimentary formations in the oil sands and heavy oil areas of Alberta. This study was completed in 1987. Because the collection of field data would be expensive, alternatives to a field program were explored. The present study was undertaken to evaluate the considerable body of data which already exists from injection well monitoring requirements in Alberta and to use them, if possible, to validate the ARC model.

PERSPECTIVE DE GESTION

Environnement Canada a accordé, depuis 1983, un certain nombre de marches au Conseil de recherches de l'Alberta (CRA) afin:

i) de définir plus précisément les contraintes géologiques et hyrologiques auxquelles est soumise l'injection souterraine de fluide;

ii) de caractériser les eaux résiduelles obtenues aux usines de récupération de pétrole lourd/des sables pétrolifères par le procédé in situ en Alberta, et qui sont actuellement évacuées par injection;

iii) d'étudier la séparation du phénol en laboratoire afin de simuler les interactions fluides résiduels-roche réservoir.

Ces études ont été faites en coordination avec le ministère de l'Environnement de l'Alberta, dont les travaux de modélisation hydrogéologique pour la région de Cold Lake avaient également été effectués par le CRA.

Reconnaissant la nécessité de vérifier les études théoriques et de laboratoire, nous nous sommes assurés de la faisabilité et du coût d'un programme de contrôle sur le terrain des effets de l'injection d'effluents dans des formations sédimentaires profondes dans des zones de sables pétrolifères et de pétrole lourd de l'Alberta. Cette étude a été réalisée en 1987. Comme la collecte des données sur le terrain serait coûteuse, nous avons exploré des possibilités de remplacement d'un programme de contrôle sur le terrain. La présente étude a été entreprise pour évaluer la somme considérable de données qui existent déjà à partir des exigences pour la contrôle des puits d'injection en Alberta et de les utiliser, si possible, pour valider le modèle du CRA.

MONITORING AND PREDICTIVE CAPABILITY FOR EVALUATING IMPACTS FROM IN-SITU OIL SAND/HEAVY OIL SUBSURFACE DISPOSAL PRACTICES

By: Stanley Associates Engineering Ltd.

For: National Hydrology Research Institute
Conservation and Protection
Environment Canada

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MONITORING AND PREDICTIVE CAPABILITY FOR EVALUATING IMPACTS FROM IN-SITU OIL SAND/HEAVY OIL SUBSURFACE DISPOSAL PRACTICES

PREPARED FOR:

NATIONAL HYDROLOGY RESEARCH INSTITUTE
INLAND WATERS DIRECTORATE
CONSERVATION AND PROTECTION
ENVIRONMENT CANADA

BY:
STANLEY ASSOCIATES ENGINEERING LIMITED
EDMONTON, ALBERTA

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30 June, 1989
File: 51-229-01-01

LETTER OF TRANSMITTAL

National Hydrology Research Institute
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5

Attention: **Mr. Gary Grove, M.Sc., P.Eng.**
Head Applied Research Section

Dear Sir:

Stanley Associates Engineering Ltd. is pleased to present the final report on Monitoring and Predictive Capability for Evaluating Impacts from In-situ Oil Sand/Heavy Oil Subsurface Disposal practices.

Yours very truly,

STANLEY ASSOCIATES ENGINEERING LTD.

D. A. Hackbarth, Ph.D., P.Geol.

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ABSTRACT

An evaluation of the pressure-volume data from 60 waste injection wells in the Cold Lake area, Alberta showed that the data cannot be used to validate pressures simulated by a finite element model, FE3DGW, developed for the area by the Alberta Research Council. Therefore, to test the predictive capabilities of the model, data from the waste injection well at the Swan Hills Special Waste Facility were used to generate simulated bottomhole pressures which were then compared with the measured values. The simulated pressures were generally 0.5 to 9 percent higher than the measured pressures which were typically 14,500 to 15,000 kPa.

Potential deep well monitoring sites in existing wells were evaluated. As well, land locations suitable for a new well site were identified.

RESUME

Une évaluation des données de pression-volume de 60 puits d'injection d'effluents dans la région de Cold Lake en Alberta a révélé que les données ne peuvent servir à valider les pressions simulées par un modèle aux éléments finis, FE3DGW, mis au point pour la région par le Conseil de recherches de l'Alberta. Par conséquent, pour vérifier la capacité de prévision du modèle, nous avons utilisé les données du puits d'injection d'effluents de la Swan Hills Special Waste Facility pour obtenir des pressions de fond de trou simulées qui ont ensuite été comparées aux mesures. Les pressions simulées étaient en générale de 0,5 à 9 pour cent plus élevées que les pressions mesurées qui oscillaient entre 14 500 et 15 000 kPa.

Des sites potentiels de contrôle des puits profonds dans des puits existants ont été évalués. En outre, des terrains propices à l'aménagement d'un nouveau puits ont été identifiés.

1.0 INTRODUCTION

Stanley Associates Engineering Ltd. (SAEL) was awarded the contract to study subsurface disposal practices in the east-central Alberta (Cold Lake area) for the National Hydrology Research Institute (NHRI), by Supply and Services Canada. The study area encompasses Townships 55 to 69 Ranges 1 to 17 west of the 4th Meridian.

The scope of the study was to:

1. Collect and evaluate pressure-volume data of the waste injection wells in the study area.
2. Predict the pressure-volume relationship in selected waste injection wells using a computer model and evaluate the computer model by comparing measured pressures to predicted pressure data.
3. Evaluate the use of existing wells within the study area to monitor the effects of waste injection on the subsurface environment.
4. Select suitable sites for construction of monitoring facilities based on the evaluation of existing monitoring and predictive capabilities.

As documented in the contract, the computer modelling will be conducted by the Basin Analysis Group, Alberta Research Council (ARC) using a finite element computer model.

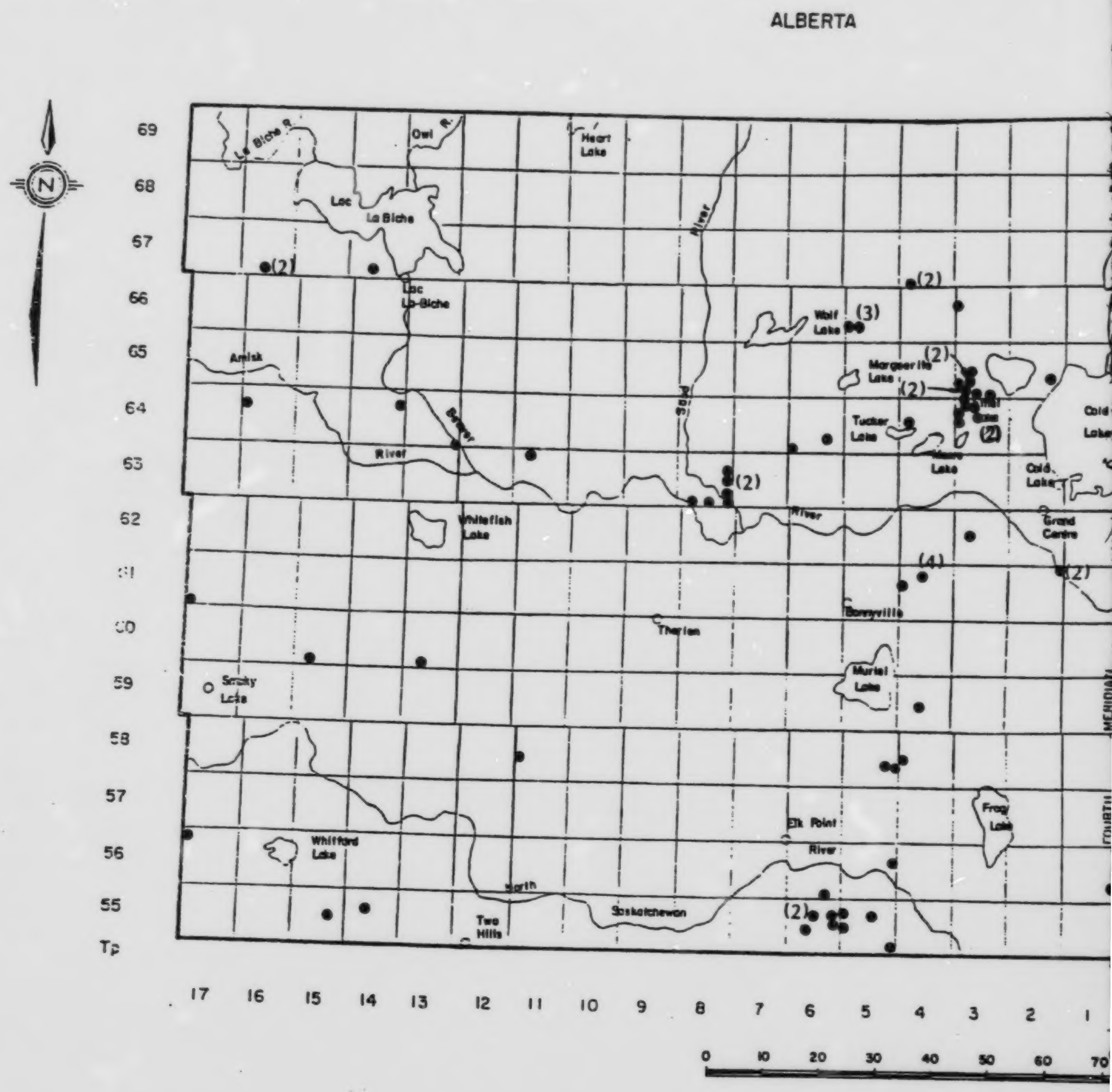
2.0 BACKGROUND

Environment Canada has been involved since 1983 in projects intended to assess the growing volume of waste being injected via disposal water wells in the Oil Sands/Heavy Oil areas of east-central Alberta (Figure 1). These projects have identified the geometry of stratigraphic units, defined hydrogeological parameters and developed a computer model of the area (Basin Analysis Group, 1985). A recent project identified constraints on the placement of monitoring locations in the area (Intera Technologies Ltd., 1987).

An industry-government workshop in September, 1987 identified concerns that the waste injection model of the ARC was unverified in terms of actual injection data. At this workshop it was suggested to find a waste injection well operator in the study area with accurate records of injected volumes and corresponding pressures. Since the Energy Resources Conservation Board (ERCB) requires the submission of disposal water well injection data, it should be possible to directly address this concern.

An interim report meeting between the Steering Committee and SAEL on June 16, 1988 resulted in the following change to the scope of the study:

1. In the interim report by SAEL (1988), it was concluded that no waste injection well in the study area could be used for computer model verification because of the lack of reliable suitable data regarding the volumes and pressures for model input. Subsequently, SAEL was asked to evaluate the pressure-volume data from the waste injection well located at the Alberta Special Waste Facility, Swan Hills, Alberta.


ALBERTA
N
La Biche R.
Owl R.
Heart Lake
Lac La Biche
Lac La Biche
Amisk
Beaver
River
Sand
River
Whitefish Lake
Wolf Lake
(3)
(2)
Margeurite Lake
(2)
Tucker Lake
Marie Lake
Cold Lake
Cold Lake
Grand Centre
(4)
(2)
Therien
Bonnyville
Smoky Lake
Muriel Lake
Frog Lake
Elk Point
River
North
Saskatchewan
Two Hills
Whitford Lake
FOURTH MERIDIAN
69
68
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65
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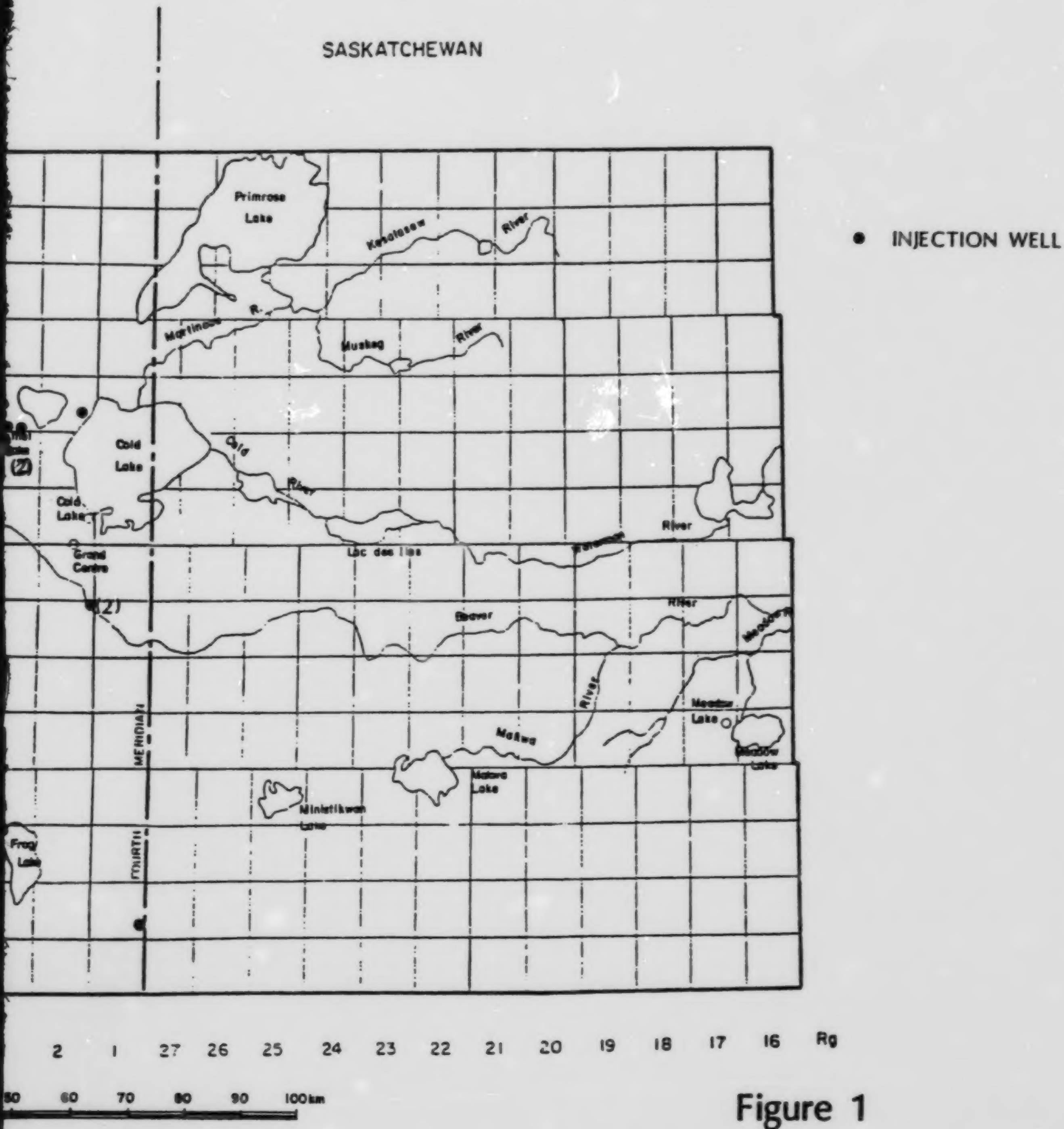

SASKATCHEWAN
● INJECTION WELL
Primrose Lake
Kesatasew River
Martineau R.
Muskeg River
Cold Lake
Cold River
Cold Lake
Grand Centre
(2)
(2)
Lac des Iles
Waterhen River
Beaver River
Meadow River
River
Makwa
Meadow Lake
Meadow Lake
Makwa Lake
Ministikwan Lake
Frog Lake
FOURTH MERIDIAN
2
1
27
26
25
24
23
22
21
20
19
18
17
16
Rg
50
60
70
80
90
100km

Figure 1

LOCATION OF INJECTION WELLS

3.0 ERCB DATA

3.1 DATA COLLECTION

The study area, located in east-central Alberta, encompasses Townships 55 to 69 and Ranges 1 to 17, west of the fourth Meridian (Figure 1). The locations of the waste injection wells in the study area were identified using microfiche data available at the ERCB. Seventy-one waste injection wells were identified in the study area. A list of waste injection wells and their data are presented in Appendix A. For the purpose of this report a water disposal well (definition used by the operators and the ERCB) will be referred to as a waste injection well.

The identification number (land location) of these wells were recorded from microfiche available at the ERCB. These well identification numbers were used to obtain the monthly injection data of each well. Injection data of each well consisting of maximum monthly pressure (wellhead pressure), total monthly injection volume and hours of injection were obtained on paper copy from the ERCB. Injection well data were available for sixty of the seventy-one injection wells.

Monthly injection volumes and hours of injection were available for all sixty wells, but the monthly pressures were either missing or not recorded consistently. Since the injection wells were operated on the "as need basis", the missing records could be attributed to the well not being used during time of measurement. Although these monthly pressure values are required to be submitted, only some of the operators follow this procedure (pers. comm. L. Schmidt, ERCB).

3.2 MONTHLY INJECTION DATA

The well characteristics (location, completion zone and depth) along with their history of injection data were entered into the Lotus 1-2-3 program. The waste injection wells were sorted based on the years of complete injection well data available from the ERCB (Appendix A). There are eleven wells with more than five year's of record; six of these have more than seven year's data, and only two have more than nine year's information.

The graphs of pressure-volume data for thirty-eight waste injection wells with a minimum of two years of pressure-volume data are presented in Appendix B. The monthly injection volumes, hours and pressure of these wells were entered into the computer using the Lotus 1-2-3 program. During data entry, it was observed that pressures and volumes appeared to be inconsistent. Graphical plots of the monthly pressure and volume data indicate large differences in pressure at similar monthly volumes. The plots between pressure and cumulative injected volume indicated similar results with no apparent correlation.

In order to test the ARC model, long-term pressure-volume data are desired as past modelling has worked in increments of five years (Basin Analysis Group, 1987). Using this criterion, the six waste injection wells with the longest period of injection data were considered for further evaluation. These waste injection wells are presented in Table 1.

TABLE 1
WASTE INJECTION WELLS

Well Identification	Operator
A2/5-28-61-4 W4	Suncor
00/10-18-58-11 W4	Dome Petroleum
00/4-17-65-3 W4	Esso Resources
02/16-36-61-2 W4	Chevron
00/8-36-61-2 W4	Chevron
02/12-4-60-15 W4	BP Resources

3.3 DAILY INJECTION DATA

Since the monthly data did not show the expected pressure-volume relationship, SAEL decided on examining the daily injection records. After notifying Environment Canada, SAEL contacted the respective operators of the waste injection wells listed in Table 1. The daily injection data were volunteered by the operators on the condition that operator name and location not be linked to data used in this report.

A telephone call and letter describing the scope of the study were used to contact the operators of the waste injection wells. In most cases the injection data were poorly organized and had to be reorganized before SAEL was able to review the data. Two operators had the data on computer files which were printed and sent to SAEL. The data for the other operators were either a hand written copy or charts. In these cases, SAEL made arrangements with the respective operators to view the injection data within their office.

A visual inspection of the daily injection data from the waste injection wells made available to SAEL by the operators resulted in the following general conclusions:

1) These waste injection wells are not operated continually, but have numerous shut-downs. Shut-down periods were dependant on the quantity of waste water needing disposal and general maintenance. Shut-down periods ranged from a few hours to months.

2) The operating license issued by the ERCB sets a maximum operating wellhead pressure for the well. Daily data of some injection wells indicate that when this maximum pressure was attained, the well was shut-down for a period of time. When the injection well was started after a shut-down period, the pressure was near zero, but appears to reach operating levels within forty-eight hours. This operating pressure is relatively constant similar to the maximum monthly pressure reported to the ERCB.

3) At one of the injection wells, the operation of the well is controlled by the quantity of waste water in the holding tank. When the liquid level attains a maximum level, the pump is activated and injection takes place until the water level drops to a selected level. The weekly charts from this injection well shows the operation of the well to be discontinuous. The pressure increases to an operating level when injection is taking place and usually decreases to near zero within forty-eight hours after the pump is off.

In summary, the injection well data available from the ERCB and confidential daily data from the respective operators did not show a correlation between volume injected and pressure recorded. Daily records indicate well injection is not continuous due to the quantity of waste water available and shut-downs for maintenance. Shut-down periods ranged from a few hours to months.

4.0 WASTE INJECTION WELL AT SWAN HILLS, ALBERTA

4.1 BACKGROUND

The waste injection well operated by Chem-Security Ltd. at the special waste plant is located near the town of Swan Hills in west-central Alberta. The waste injection well (CSL - Ethel 13-6-67-8-W5M) was drilled in 1986 to a depth of 2040 m. A schematic detailed drawing of the well is presented in Figure 2.

The hydrostratigraphic delineation of the lithologic units is presented in Table 2. A detailed description of these hydrostratigraphic units is given in the ARC report (Appendix C). The injection of waste liquids takes place in the Blue Ridge Formation of the Winterburn Group, Upper Devonian, in perforated intervals at 1912.5 - 1917.5, 1919 - 1923, 1924 - 1925, 1933 - 1934 and 1938-1944 metres depth.

The waste injection well is operated by Chem-Security Ltd. and is used for the disposal of waste fluids generated by the Alberta Waste Management Facility. Waste injection is not continuous, but on an "as needed" basis. The specific gravity of the waste fluid is generally 1.00 and the pH of the waste fluid ranges from acidic (1) to basic (13).

4.2 INJECTION WELL DATA

The injection well data from the Alberta Special Waste facility was recorded daily using the following parameters:

a)	Bottomhole pressure	kPa
b)	Wellhead pressure	kPa
c)	Temperature of injected fluid	°C
d)	pH	
e)	Flow rate	m^3/hr
f)	Specific gravity	
g)	Suspended solids	ppm
h)	Dissolved solids	ppm

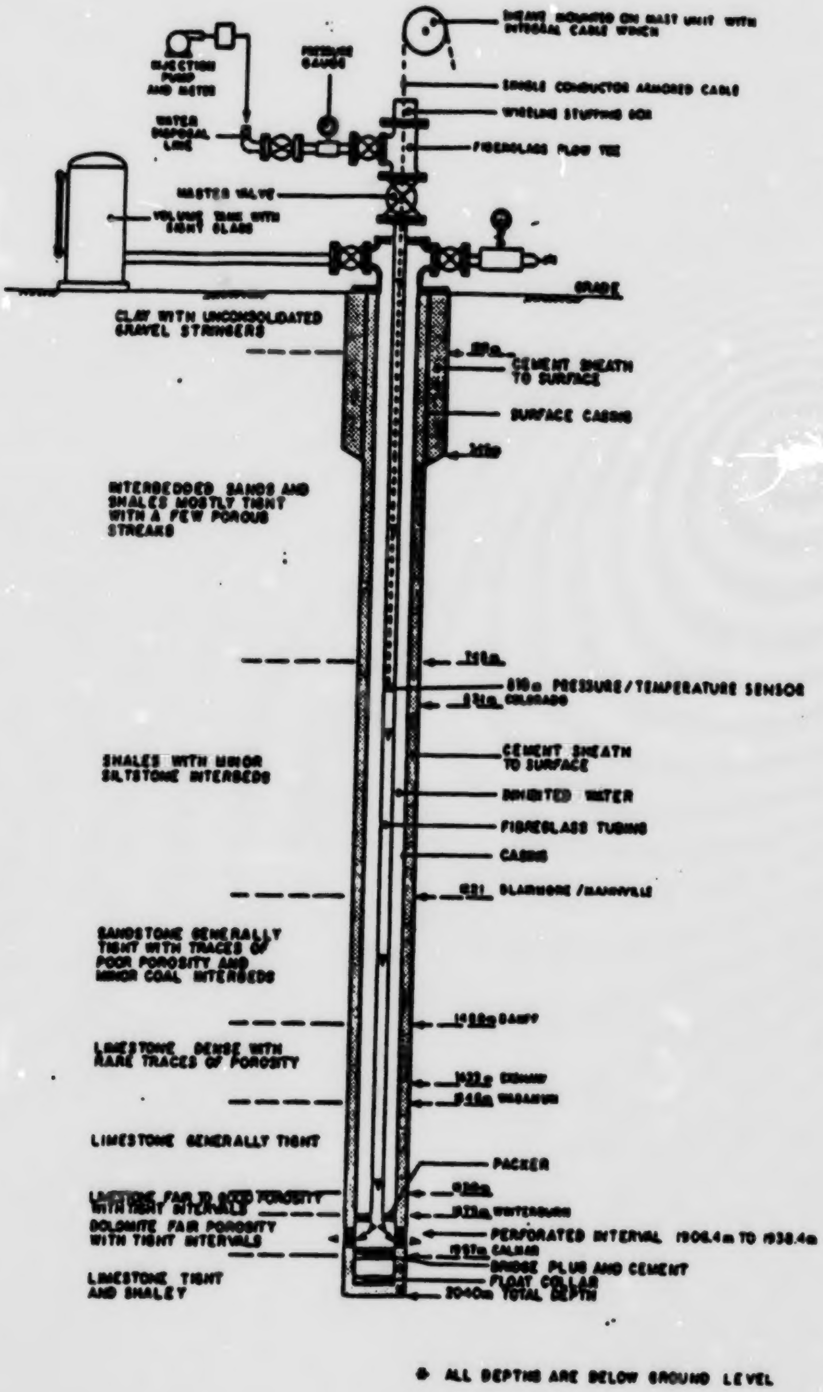

SHEAVE MOUNTED ON MAST UNIT WITH INTEGRAL CABLE WINCH
PRESSURE GAUGE
INJECTION PUMP AND METER
SINGLE CONDUCTOR ARMORED CABLE
WIRELINE STUFFING BOX
WATER DISPOSAL LINE
FIBERGLASS FLOW TEE
MASTER VALVE
VOLUME TANK WITH SIGHT GLASS
GRADE
CLAY WITH UNCONSOLIDATED GRAVEL STRINGERS
CEMENT SHEATH TO SURFACE
SURFACE CASING
INTERBEDDED SANDS AND SHALES MOSTLY TIGHT WITH A FEW POROUS STREAKS
810m PRESSURE/TEMPERATURE SENSOR
COLORADO
SHALES WITH MINOR SILTSTONE INTERBEDS
CEMENT SHEATH TO SURFACE
INHIBITED WATER
FIBREGLASS TUBING
CASING
BLAIRMORE/MANNVILLE
SANDSTONE GENERALLY TIGHT WITH TRACES OF POOR POROSITY AND MINOR COAL INTERBEDS
BANFF
LIMESTONE DENSE WITH RARE TRACES OF POROSITY
EXSHAW
WABAMUN
LIMESTONE GENERALLY TIGHT
PACKER
LIMESTONE FAIR TO GOOD POROSITY WITH TIGHT INTERVALS
WINTERBURN
DOLOMITE FAIR POROSITY WITH TIGHT INTERVALS
PERFORATED INTERVAL 1906.4m TO 1938.4m
CALMAR
LIMESTONE TIGHT AND SHALEY
BRIDGE PLUG AND CEMENT
FLOAT COLLAR
2040m TOTAL DEPTH
* ALL DEPTHS ARE BELOW GROUND LEVEL

Figure 2

WASTE WATER DISPOSAL WELL

i)	Total organic carbon	ppm
j)	Operating time	hrs
k)	Volume injected	m^3

Two sets of injection well data were made available by Chem-Security Ltd. to SAEL for evaluation.

1. Injection Data I consists of daily data from April 24 to June 29, 1988. In this data set, bottomhole pressures were measured immediately following injection.

   It was determined that this data set was not representative of non-pumping static conditions because time would be needed for the bottomhole pressure to equilibriate after injection.

2. Injection Data II consists of data from October 18 to November 30, 1988. In this data set, bottomhole pressures were recorded one-half hour following injection to better represent the daily static pressures of the injection well; and eliminate the effects of back pressure on the recorder.

TABLE 2

HYDROSTRATIGRAPHIC DELINEATION AT THE WASTE INJECTION WELL (BASIN ANALYSIS GROUP, APPENDIX C)

Period	Top	Stratigraphic Depth	Elevation	Lithology	% Shale	Hydrostratigraphic Unit
	GROUND SURFACE	0	1086	N/A	N/A	N/A
CRETACEOUS		351	740	SAND/SHALE	40	--------
	BELLY RIVER	413	678	SAND/SHALE	30	AQUIFER
		682	409	SAND/SHALE	20	
	LEA PARK	780	311	SHALE/SAND	50	
	COLORADO SHALE	830	261	SHALE/SAND	70	AQUITARD
		863	228	SAND/SHALE	45	
	BAD HEART	883	208	SAND/SHALE	30	AQUIFER
	MUSKIKI	887	204	SHALE/SAND	50	
	2WS	988	103	SHALE/SAND	65	
		1035	56	SHALE	80	AQUITARD
		1045	46	SHALE/SAND	55	
		1133	-42	SHALE/SAND	65	
	BFS	1152	-61	SHALE/SAND	55	
	VIKING	1205	-114	SAND/SHALE	45	
	JOLI FOU	1213	-122	SHALE/SAND	70	
	MANNVILLE	1228	-137	SAND/SHALE	30	
		1380	-289	SAND/SHALE	40	AQUIFER
	GETHING	1402	-311	SAND/SHALE	30	
		1487	-396	SAND	0	
MISS	BANFF	1505	-414	CARB/SHALE	10	
		1527	-436	CARB/SHALE	30	
		1585	-494	SHALE/CARB	70	AQUITARD
		1605	-514	CARB	0	AQUIFER
		1617	-526	CARB/SHALE	25	
	EXSHAW	1638	-547	SHALE	100	
DEVONIAN		1640	-549	CARB	20	AQUITARD
		1645	-554	SHALE	100	
	WABAMUN	1651	-560	CARB	0	
	GRAMINIA	1896	-805	CARB	10	AQUIFER
	BLUE RIDGE	1905*	-814	CARB	5	
		1925*	-834	CARB	10	
	CALMAR	1950	-859	CARB/SHALE	50	WEAK AQUITARD
	NISKU	1968	-877	CARB	10	
		1975	-884	CARB	0	AQUIFER
		1983	-892	CARB	10	
		2005	-914	CARB/SHALE	35	WEAK AQUITARD
	IRETON	2030	-939	SHALE	N/A	AQUITARD

* injection interval

N/A not available

5.0 COMPUTER MODELING

5.1 COMPUTER MODEL

The computer model FE3DGW (Gupta et al, 1984a, 1984b) was used to conduct the simulation of bottomhole pressures in the waste injection well. This particular model was used in simulations conducted in the study area (Basin Analysis Group, 1987), and at the Alberta Special Waste Facility prior to the injection of waste fluids (Basin Analysis Group, 1985). A detailed description of the model and the methodology involved during the modelling is described by the ARC report (Appendix C).

5.2 INPUT DATA

The hydraulic parameter values used during the simulations are calculated in Appendix C and tabulated in Table 3. Two sets of hydraulic parameters, based on drillstem tests (DSTs) and core analyses, were simulated. The first simulation was run considering the lower-most limit of hydraulic characteristic values and the second run using the upper-most limit of hydraulic characteristics.

As discussed in a previous section, two sets of injection data were obtained from Chem-Security Ltd. The injection data were reorganized by SAEL with daily injection volumes and time intervals, and presented to Basin Analysis Group (ARC) for computer modelling. The numerous peaks and lows of daily data were averaged using a 3-day interval to smooth the data which would facilitate the comparison of actual bottomhole pressure data and simulated pressures. The bottomhole pressures were calculated using a 3-day moving average. For the purpose of testing the computer model against actual data, the averaging of the injection data was deemed necessary to eliminate daily irregularities in the bottomhole pressures. These two sets of injection data are presented in Tables 4 and 5. Bottomhole pressures were retained by SAEL to compare with the predicted bottomhole pressures simulated by the ARC model. ARC was not aware of the actual pressure measurements.

TABLE 3

VALUES OF PERMEABILITY AND SPECIFIC STORAGE USED IN COMPUTER SIMULATIONS

Hydrostratigraphic Unit	Low Values of Hydraulic Parameters			High Values of Hydraulic Parameters		
	K_h (m^2)	k_v (m^2)	S_s (m^{-1})	K_h (m^2)	K_v (m^2)	S_s (m^{-1})
Wabamum	5.3×10^{-15}	1.0×10^{-15}	1.2×10^{-4}	1.2×10^{-14}	0.95×10^{-14}	3.2×10^{-4}
Upper Winterburn	5.3×10^{-15}	1.0×10^{-15}	1.2×10^{-4}	5.5×10^{-14}	1.05×10^{-14}	1.2×10^{-4}
Blue Ridge	5.3×10^{-15}	1.0×10^{-15}	1.2×10^{-4}	5.5×10^{-14}	1.05×10^{-14}	1.2×10^{-4}
Calmar	2.5×10^{-17}	1.0×10^{-17}	1.2×10^{-4}	2.5×10^{-17}	1.00×10^{-17}	1.2×10^{-4}
Upper Nisku	3.8×10^{-15}	0.7×10^{-15}	1.2×10^{-4}			
Lower Nisku	2.0×10^{-17}	1.0×10^{-17}	1.2×10^{-4}			

TABLE 4
VOLUME OF WASTE INJECTED

Time Step (1988)	Date (1988)		Injection Rate (m^3/3 days)	Bottomhole[a] Pressure (kPa)
1	April	24	458	14385
2		27	399	14930
3		30	421	14614
4	May	3	811	N/A
5		6	700	N/A
6		9	1075	16120
7		12	1260	N/A
8		15	447	N/A
9		18	1139	15860
10		21	1089	15947
11		24	1080	16131
12		27	898	16077
13		30	1254	16222
14	June	2	1651	17661
15		5	1476	17830
16		8	900	16207
17		11	1009	N/A
18		14	282	N/A
19		17	198	15912
20		20	1040	16740
21		23	881	16386
22		26	1040	16699
23		29	1065	17390

[a] - 3 day moving average

TABLE 5

VOLUME OF WASTE INJECTED: OCTOBER 18 TO NOVEMBER 30, 1988

Time Step	Date	Injection Rate (m³/d)	Bottom[a] hole Pressure (kPa)
1	Oct. 18	234.00	14706
2	19	256.00	14800
3	20	227.00	N/A
4	21	235.00	14925
5	22	293.00	14800
6	23	226.00	14936
7	24	227.00	14929
8	25	210.00	14704
9	26	147.00	14574
10	27	196.00	14762
11	28	188.00	14733
12	29	229.00	14743
13	30	150.00	14791
14	31	75.00	14913
15	Nov. 1	185.00	14788
16	2	208.00	14882
17	3	229.00	14723
18	4	295.00	14838
19	5	276.00	14923
20	6	270.00	14843
21	7	280.00	14915
22	8	232.00	14923
23	9	220.00	14823
24	10	185.00	14918
25	11	212.00	14905
26	12	299.00	14873
27	13	198.00	14890
28	14	284.00	14923
29	15	290.00	14897
30	16	288.00	14753
31	17	204.00	14773
32	18	217.00	14776
33	19	198.00	14844
34	20	209.00	14829
35	21	211.00	14814
36	22	225.00	14852
37	23	218.00	14753
38	24	201.00	14770
39	25	288.00	14780
40	26	293.00	14817
41	27	293.00	14834
42	28	302.00	14843
43	29	223.00	14801
44	30	215.00	14859

[a] 3 day moving average

5.3 MODELLING RESULTS

In this report the computer modelling of Injection Data I and Injection Data II will be referred to as Simulation I and Simulation II, respectively.

It should be recognized that the ARC model predicts pressures in what may be considered as a small, but finite, piece of the injection zone. The actual pressures, by contrast, must be considered to be point-based or representing an almost infinitely small piece of the injection zone. Therefore, all things being correctly simulated, this ARC model will tend to predict lower pressures than the actual.

5.3.1 Simulation I

The results of Simulation I and the measured bottomhole pressure data are presented in Figure 3. As shown in Figure 3, simulated bottomhole pressure data using the low hydraulic characteristics over-estimated the measured bottomhole pressures. However, the bottomhole pressures simulated using the high hydraulic characteristics were similar to the measured bottomhole pressures. During time steps 1 to 13 (April 22 to May 30) the simulated bottomhole pressures were 2 to 9% higher than the measured data. After time step 13 the simulated values fluctuated (0.5 to 6%) along the measured data.

5.3.2 Simulation II

As with Simulation I, the simulated bottomhole pressure data using the low hydraulic characteristics over-estimated the measured bottomhole pressures (Figure 4). As shown in Figure 4, the simulated bottomhole pressures were (0.50 to 3.74%) higher than the measured bottomhole pressures using the high values of hydraulic parameters.

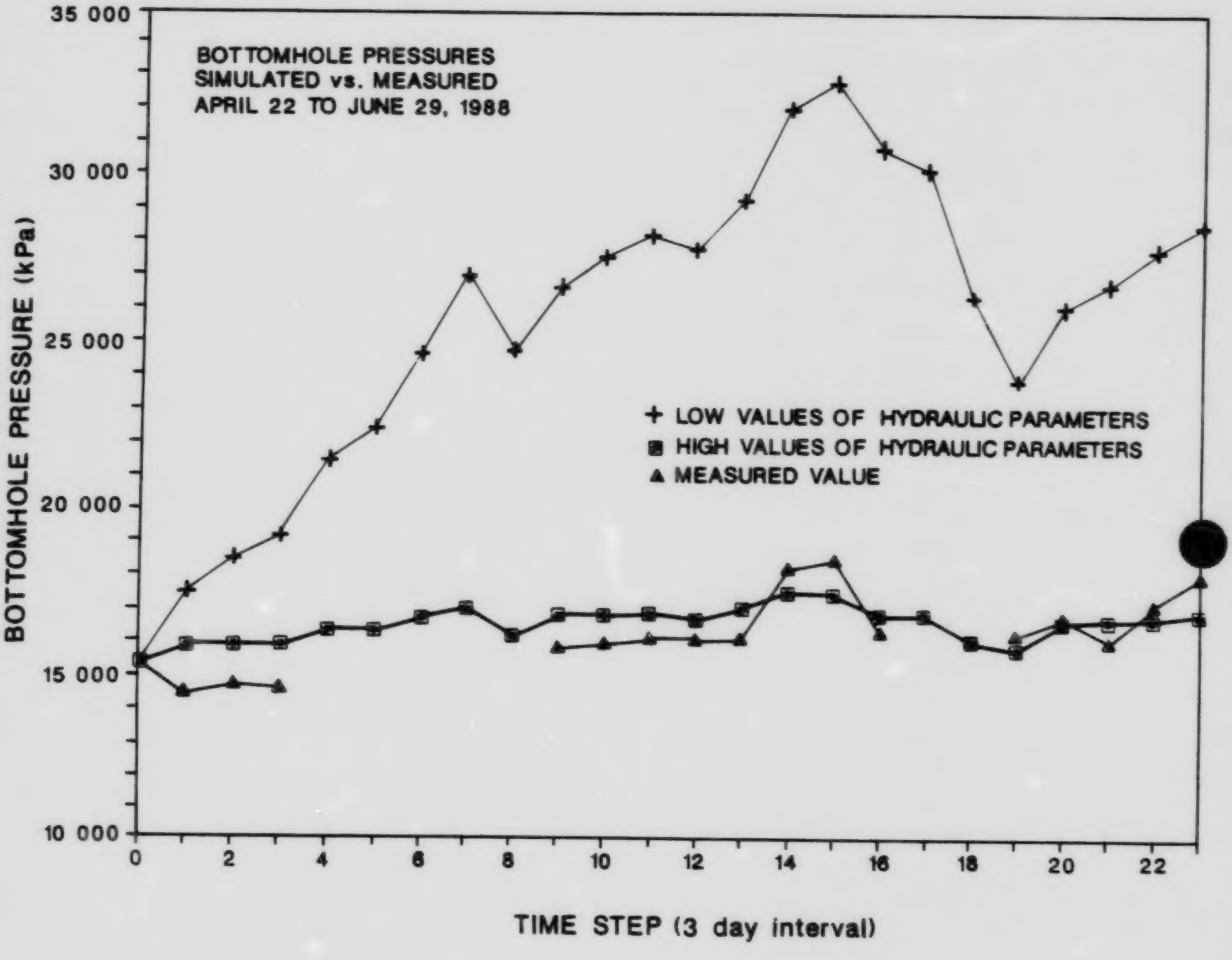


Figure 3

BOTTOMHOLE PRESSURES:
SIMULATED vs. MEASURED;
APRIL 22 TO JUNE 29, 1988

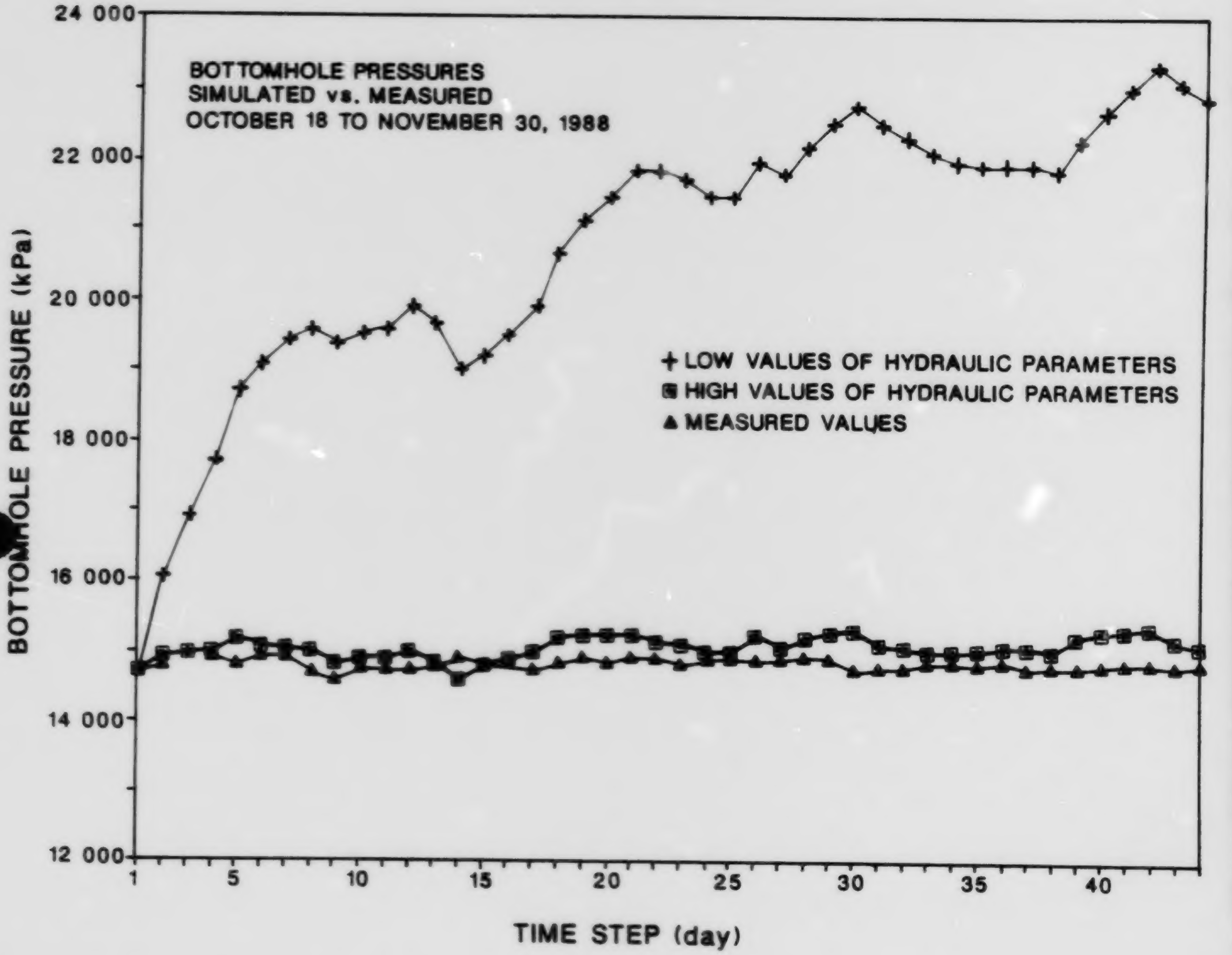


Figure 4

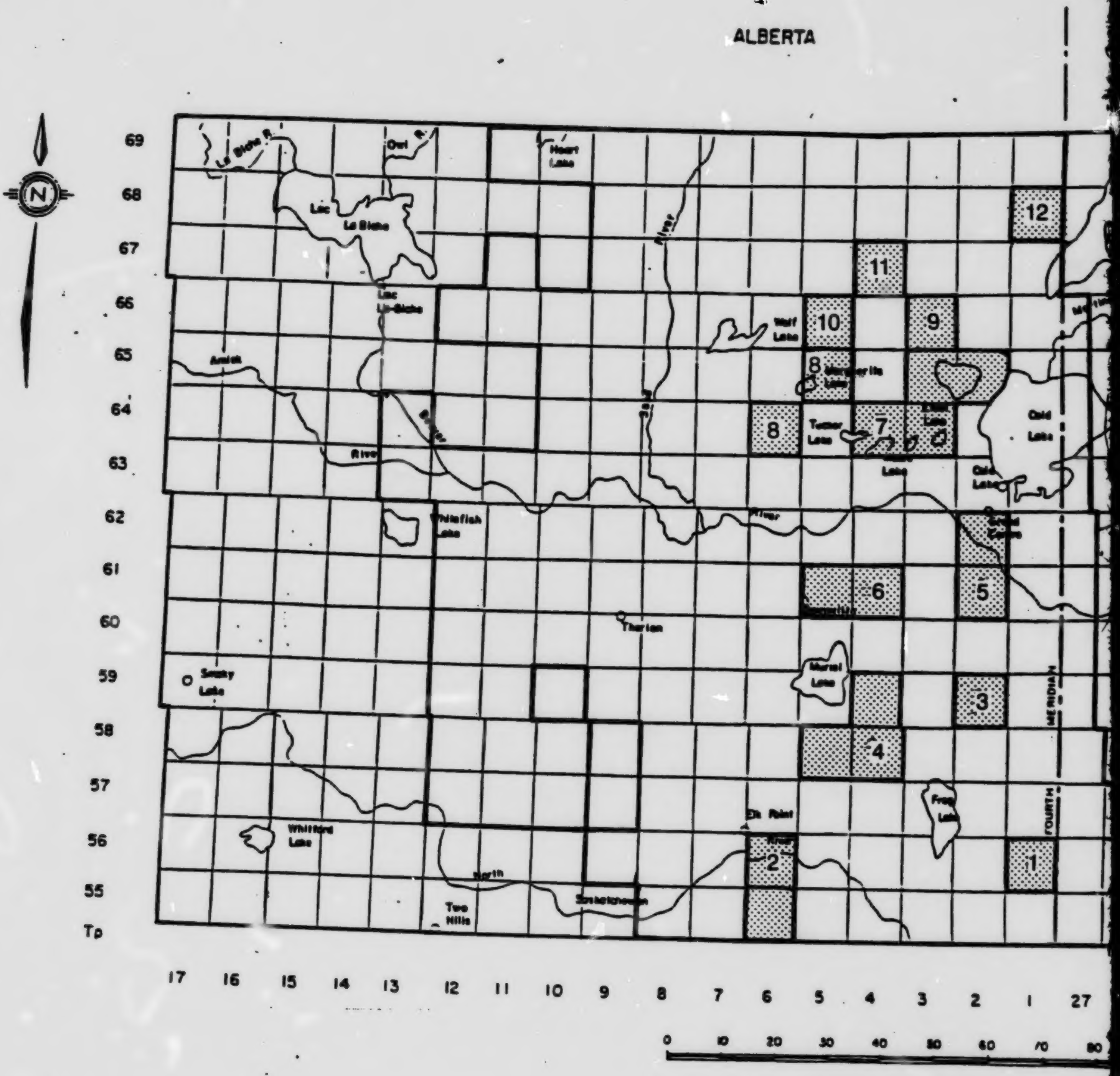
BOTTOMHOLE PRESSURES: SIMULATED vs. MEASURED; OCTOBER 18 TO NOVEMBER 30, 1988

6.0 POTENTIAL MONITORING WELLS

6.1 EXISTING WELLS

In Townships where oil and/or gas wells currently exist, it was considered possible that these wells could be recompleted as monitoring wells. A review of the PIX (Canadian Petroleum Information Exchange) cards was conducted to determine the number of potential monitoring wells in the high preference areas identified by the Intera 1987 Study (Figure 5). The distribution of wells that are completed or penetrate the injection zones in the high preference areas are tabulated in Table 6. Each of the high preference areas are identified using a numeric system to facilitate the identification and ranking of the 12 areas.

A dBase matrix consisting of the variables tabulated in Table 7 was structured to record the information available on the PIX cards. As shown in Table 6, some Townships have numerous potential monitoring wells, which resulted in more than one well per section. Instead of entering all the potential monitoring wells presented in Table 6, a representative well was chosen from sections where there was more than one potential monitoring well. The representative well was selected based on the maximum filling of the dBase matrix in Table 7. A list of the wells examined are presented in Appendix D.


ALBERTA
N
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
Tp
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
27
0
10
20
30
40
50
60
70
80
La Biche R.
Owl R.
Heart Lake
Lac La Biche
Lac La Biche
Amisk
Beaver
River
Sand
River
Wolf Lake
Marguerite Lake
Tucker Lake
Cold Lake
Cold Lake
Grand Centre
River
Whitefish Lake
Therien
Smoky Lake
Muriel Lake
Frog Lake
Elk Point
River
Whitford Lake
North
Saskatchewan
Two Hills
FOURTH MERIDIAN
12
11
10
9
8
8
7
6
5
4
3
2
1

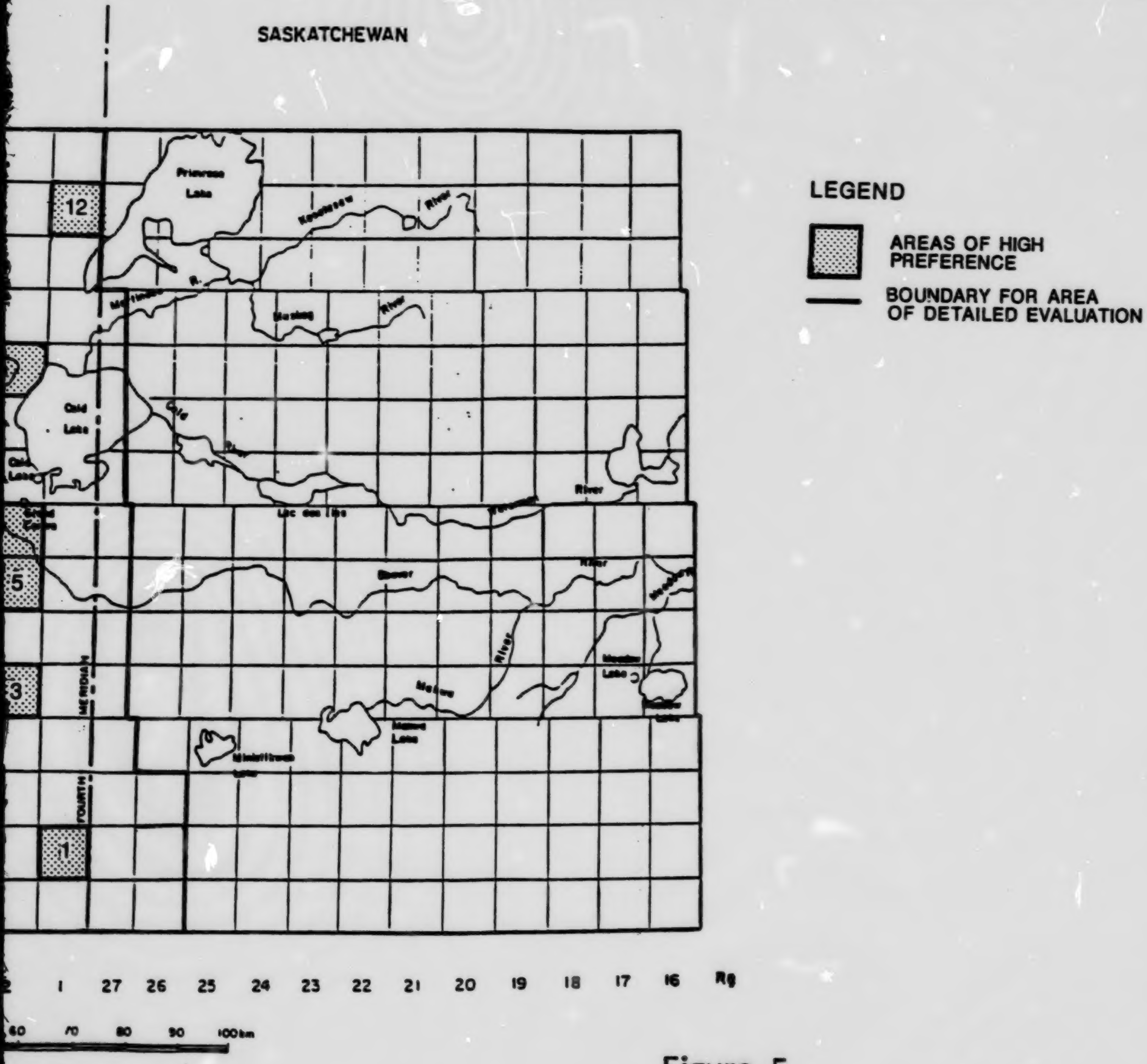

SASKATCHEWAN
12
Primrose
Lake
R.
River
River
Cold
Lake
Lac des Iles
River
5
Beaver
River
River
River
3
Meadow
Lake
Makwa
Lake
Lake
MERIDIAN
FOURTH
1
2
1
27
26
25
24
23
22
21
20
19
18
17
16
Rg
60
70
80
90
100km
LEGEND
AREAS OF HIGH PREFERENCE
BOUNDARY FOR AREA OF DETAILED EVALUATION

Figure 5

HIGH PREFERENCE AREAS
FOR MONITORING IMPACT
OF WASTE FLUID INJECTION,
INTERA STUDY, 1987

TABLE 6

DISTRIBUTION OF WASTE INJECTION AND POTENTIAL MONITORING WELLS

Area	Township	Range	Number of Injection Wells	Total Number of Available Wells
1	56	1	1	15
2	56	6	1	147
	55	6	5	522
3	59	2	0	6
4	58	4	1	11
	58	5	2	6
	59	4	1	14
5	61	2	2	5
	62	2	0	1
6	61	4	5	7
	61	5	0	10
7	64	3	8	7
	64	4	1	18
	65	2	1	4
	65	3	7	8
8	64	6	2	8
	65	5	0	12
9	66	3	1	2
10	66	5	4	168
11	67	4	2	20
12	68	1	0	0

TABLE 7
EXISTING MONITORING WELL dBASE FILE

LOCATION		Well CSD
OWNER		Owner/operator of well
WELLNAME		Description well name
SURFRIGHT		Surface rights
SPUDDATE		Spud date
STATUS		Oil, gas, water, etc.
UNITS		Hole depth units
TOTDEPTH		Total Depth
PRODZONE		Production Zone
FM	1	Formation name
	2	Formation name
	3	Formation name
	4	Formation name
	5	Formation name
	6	Formation name
	7	Formation name
	8	Formation name
	9	Formation name
	10	Formation name
TOP FM	1	Depth to top of FM1
	2	Depth to top of FM2
	3	Depth to top of FM3
	4	Depth to top of FM4
	5	Depth to top of FM5
	6	Depth to top of FM6
	7	Depth to top of FM7
	8	Depth to top of FM8
	9	Depth to top of FM9
	10	Depth to top of FM10
DST	1	T - DST Conducted, F - No DST conducted
	2	T - DST Conducted, F - No DST conducted
	3	T - DST Conducted, F - No DST conducted
	4	T - DST Conducted, F - No DST conducted
	5	T - DST Conducted, F - No DST conducted
	6	T - DST Conducted, F - No DST conducted
	7	T - DST Conducted, F - No DST conducted
	8	T - DST Conducted, F - No DST conducted
	9	T - DST Conducted, F - No DST conducted
	10	T - DST Conducted, F - No DST conducted
LOGS		Types of geophysical logs run
CORE		If core analysis were conducted
PERF	1	T - Perforated, F - not perforated
	2	T - Perforated, F - not perforated
	3	T - Perforated, F - not perforated
	4	T - Perforated, F - not perforated
	5	T - Perforated, F - not perforated
	6	T - Perforated, F - not perforated
	7	T - Perforated, F - not perforated
	8	T - Perforated, F - not perforated
	9	T - Perforated, F - not perforated
	10	T - Perforated, F - not perforated
IP		Production interval
PRODHIST		Availability of production history records
NETPAYS		Availability of net payload thickness records

AREA 1 (Tp 56, R1, W4M)

Potential monitoring wells in Area 1 consist mostly of shut-in gas wells. DST data are generally available for the Colony and Grand Rapids Formations. Geophysical logs were conducted on most of the wells.

Waste injection occurs in the Mannville Group which consists of the Colony and Grand Rapids Formations.

AREA 2 (Tp 55, R6, W4M)
(Tp 56, R6, W4M)

The majority of the potential monitoring wells in Area 2 are crude bitumen wells used for heavy oil production in the area. Most of them have geophysical logs and are perforated in the Colony and Cummings Formations. DST data are available for the Viking, Colony and Mannville sequence along with a few core analyses.

Waste injection takes place in the Mannville and Cooking Lake, Beaverhill Lake-Watt Mountain Groups. The total depth of the potential monitoring wells are generally 600 m, which indicates the majority of these wells penetrate the waste injection units.

AREA 3 (Tp 59, R2, W4M)

There are six potential monitoring wells in Area 3. The monitoring wells consist of four shut-in gas wells, a gas well and an experimental well. Geophysical logs are available for most of the wells along with DST data on the Colony and Sparky Formations. However, there are no waste injection wells in Area 3.

AREA 4 (Tp 58, R4, W4M)
(Tp 58, R5, W4M)
(Tp 59, R4, W4M)

Potential monitoring wells in Area 4 consist of shut-in gas, gas, shut-in oil, and oil wells. Geophysical logs were conducted in most wells and DST data are available for the Colony and Sparky Formations.

Waste injection occurs in the Mannville and Cooking Lake Beaverhill Lake-Watt Mountain Groups. The total depths of potential monitoring wells range from 459 to 642 m which indicates that a large number of these wells penetrate the waste injection units.

AREA 5 (Tp 61, R2, W4M)
(Tp 62, R2, W4M)

Potential monitoring wells in Area 5 consist of three shut-in gas, gas and an observation well. Geophysical logging was conducted, but no DST data are available for this area.

Waste injection takes place in the Mannville Group. The total depths of the wells which range from 465 to 510 m penetrate into the Mannville Group.

AREA 6 (Tp 61, R4, W4M)
(Tp 61, R5, W4M)

Potential monitoring wells in Area 6 consist of gas, suspended gas and an observation well. Geophysical logs were conducted in most of the wells and DST's were performed in the Mannville Group. All these wells penetrate the Mannville Group which is the waste injection zone in this area.

AREA 7 (Tp 64, R3, W4M)
(Tp 64, R4, W4M)
(Tp 65, R2, W4M)
(Tp 65, R3, W4M)

Potential monitoring wells in Area 7 consist of suspended wells (gas and cyclical), gas, and cyclical (steam injection) wells. Core and geophysical data are available along with limited DST data from the Grand Rapids and Clearwater Formations.

Waste injection takes place in the Mannville Group and Deadwood/Granite Wash. All of the potential monitoring wells penetrate the Mannville Group, but none reach the Deadwood/Granite Wash.

AREA 8 (Tp 65, R5, W4M)
(Tp 64, R6, W4M)

Potential monitoring wells in Area 8 consist of gas, suspended gas, cyclical and an observation well. Numerous DST's were conducted on the Colony, Sparky and Clearwater Formations. Geophysical logging was conducted in all the wells.

Waste injection takes place in the Mannville Group and Deadwood/Granite Wash. All the potential monitoring wells penetrate the Mannville Group, but none reach the Deadwood/Granite Wash.

AREA 9 (Tp 66, R3, W4M)

Only 2 potential monitoring wells exist in Area 9. These wells consist of a shut-in gas and a heavy oil well drilled and geophysically logged to a total depths of 547 and 608 m, respectively.

Based on the perforated zone of the waste injection well, waste injection takes place in the Mannville Group.

AREA 10 (Tp 66, R5, W4M)

The majority of the monitoring wells in the area consist of gas wells and one observation well. Geophysical logs were conducted in most of the wells along with limited DST data.

Waste injection takes place in the Mannville Group and Deadwood/Granite Wash. The total depth of these potential monitoring wells indicate that they only penetrate the Mannville Group.

AREA 11 (Tp 67, R4, W4M)

Potential monitoring wells in Area 11 consist of shut-in gas and oil wells. Geophysical logs were conducted in most of the wells, with DST's conducted in the Colony Formation.

Waste injection takes place in the Mannville Group and the Deadwood/Granite Wash. The total depth of these potential monitoring wells indicate they only penetrate the Mannville Group.

Waste injection takes place in the Mannville Group and the Deadwood/Granite Wash. The total depth of these potential monitoring wells indicate they only penetrate the Mannville Group.

AREA 12 (Tp 68, R1, W4M)

No existing wells or waste injection well were present in this area.

In general, the following are summary comments of existing potential monitoring wells.

a) The majority of the wells in the high preference areas are gas wells (shut-in, flowing) followed by oil wells, experimental and observation wells.

b) At least one geophysical log of some sort was conducted in nearly all the wells.

c) Good DST data and a few core analyses are available for the Mannville Group.

d) Most of the existing wells penetrate the Mannville Group waste disposal unit.

e) No existing potential monitoring wells penetrate the Deadwood/Granite Wash waste disposal unit.

6.1.1 Limitations of Using Existing Wells for Monitoring Waste Injection

The ERCB specifies that following drilling, a drill rig cannot be moved from the borehole until either a casing is installed or the well is cemented. Therefore, no uncased hole exists for use as a monitoring well with the exception of core holes (which can be left uncased) and plugged holes. If a hole has been plugged for five years, the re-entry of holes is reported to have no cost advantage over drilling a new hole (Zenon, 1983). Therefore, only cased holes exist. In order to use a cased hole, it must be recompleted in the zone of interest by perforating the casing which may have a number of implications regarding geochemical sampling and hydraulic testing. Geochemical sampling may show trace residual effects of the perforating including iron, tungsten, copper, nickel, and chromium. A light acid wash will reduce the concentrations of these trace residuals to a level that may or may not be detectable. Perforating can effect hydraulic testing by either providing insufficient openings to determine formation permeability or by glazing of the formation (e.g. in limestone) by the perforating jet. Again a light acid wash will reduce most of the effects caused by glazing.

Prior to the abandonment of production wells (oil and gas) the ERCB requires that a bridge plug be placed within the production tubing just above the perforations followed by a minimum of 8 m of cement. A pressure test is also required to ensure the cement plug is stable. The production tubing is filled with a corrosion-inhibiting fluid cut-off and sealed with cement at 1 m below ground surface.

Though there are numerous existing hydrocarbon (gas, shut-in gas, oil, shut-in oil, and cyclical) wells in the study area, the use of an existing well as a monitor would be difficult since the wells are being used for hydrocarbon production. Also, the existing well must be recompleted in the zone of interest by perforating the casing which may have a number of implications regarding geochemical sampling and hydraulic testing.

6.1.2 Observation Wells

Active observation wells based on the 1989 list of wells (ERCB) in the area could be likely candidates for monitoring wells. The location and completion zone of these observation wells are presented in Table 8.

A computer search of the ERCB files indicated the data for these observation wells to have the following:

i) Casing to total depth.
ii) Geologic and geophysical logs.
iii) No DST or core data.
iv) No data on perforated zones and geochemical treatments.

However, these are a number of those wells completed in the Mannville Group, and should be considered as potential candidates to monitor the effects of waste injection on subsurface conditions. The highest density area of observation wells is Area 7, at which there are 46 wells being operated by Esso Resources and Bow Valley Industries.

TABLE 8

OBSERVATION WELLS

Area	Location	Number of Wells	Owner/ Operator	Depth (m)
1	11-56-01 W4	3	Hudson Bay	677-680
2	13-55-06 W4	1	Westmin	640
7	27-64-03 W4	8	Esso Resources	684-511
	14-65-02 W4	2	Bow Valley	457-466
	04-65-03 W4	2	Esso Resources	532-535
	05-65-03 W4	16	Esso Resources	504-533
	06-65-03 W4	4	Esso Resources	481-504
	07-65-03 W4	8	Esso Resources	471-500
	08-65-03 W4	6	Esso Resources	464-565
8	08-65-05 W4	2	BP Exploration	484-485
	32-65-05 W4	2	BP Exploration	325

6.2 SELECTION OF POTENTIAL NEW MONITORING WELL SITES

The high preference areas identified by the Intera study (1987) were evaluated to determine their value as a monitoring site. These areas were delineated based on the criteria in Table 10. Based on the criteria already established in Table 10, SAEL evaluated these high preference areas with the additional criteria listed in Table 9.

TABLE 9
ADDITIONAL MONITORING SITE CRITERIA

Criteria	Description
Power	Electrical power (Alberta Power)
Road	All weather road (NTS Maps)
Proximity	Distance to injection well

The following two areas were not considered for further evaluations due to the following reasons:

Area 3

No waste injection wells exist in this area.

Area 12

No waste injection wells exist in this area.

Each section of land within the remaining ten high preference areas (1, 2 and 4 to 11) were evaluated with the additional criteria.

Based on the computer modelling conducted by the Basin Analysis Group, ARC, pressure increases in the subsurface are relatively small when the high hydraulic characteristics were used in the simulations. A comparison of simulated bottomhole pressures and measured bottomhole pressures of the Swan Hills injection well indicates the high hydraulic characteristics produced simulated pressures most similar to the measured pressures. Therefore, to monitor the impact of waste injection, monitoring wells should be located near (<3.2 km or 2 miles) existing injection wells to effectively monitor the effects of waste injection.

The areas that meet these additional criteria are delineated in Figure 6 and tabulated in Table 11. Based on the Intera Study (1987) and data collected during this study, the areas delineated in Figure 6 are the most suitable areas for establishing new sites to monitor the impact of waste injection.

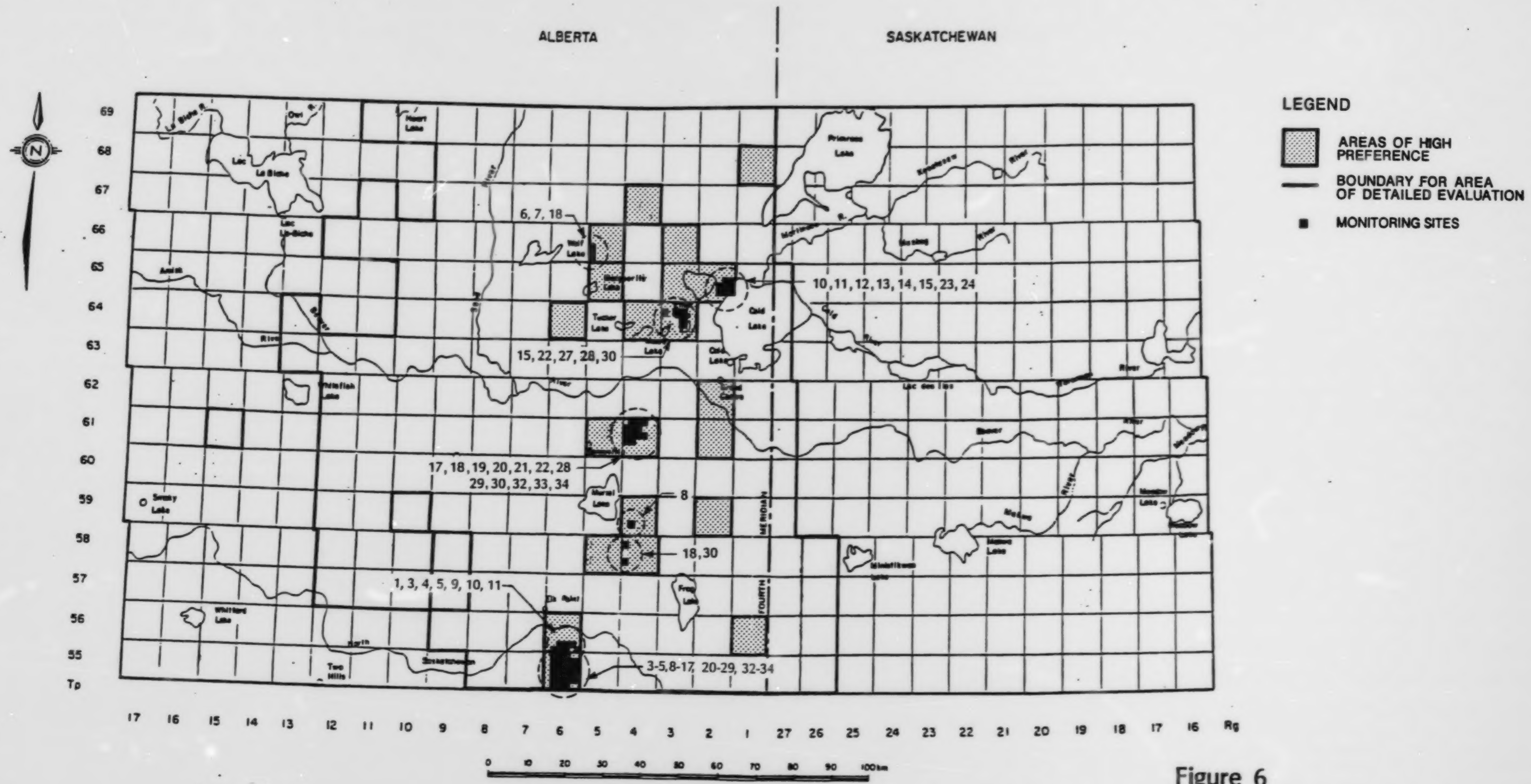

ALBERTA
SASKATCHEWAN
LEGEND
AREAS OF HIGH PREFERENCE
BOUNDARY FOR AREA OF DETAILED EVALUATION
MONITORING SITES
N
6, 7, 18
10, 11, 12, 13, 14, 15, 23, 24
15, 22, 27, 28, 30
17, 18, 19, 20, 21, 22, 28
29, 30, 32, 33, 34
8
18,30
1, 3, 4, 5, 9, 10, 11
3-5, 8-17, 20-29, 32-34
Primrose Lake
Lac La Biche
Lac La Biche
Cold Lake
Wolf Lake
Marie Lake
Frog Lake
Whitford Lake
Smoky Lake
Whitefish Lake
Two Hills
Elk Point
North Saskatchewan
Amisk
Beaver River
FOURTH MERIDIAN
Lac des Iles
Makwa Lake
Tp
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
27
26
25
24
23
22
21
20
19
18
17
16
Rg
0
10
20
30
40
50
60
70
80
90
100km

Figure 6

NEW SITES FOR MONITORING THE IMPACT OF WASTE FLUID INJECTION

TABLE 10
CRITERIA FOR SITING A MOITORING SYSTEM TO ASSESS WASTE INJECTION IMPACTS
(AFTER INTERA (1987))

	Assessment Criteria	Designation and Weighting*		
A.	Geologic Information:			
A1.	Proximity to Major Structural Influences on Groundwater Flow	>20 km (1)	5 - 20 km (3)	0 - 5 km (5)
B.	Hydrogeologic Information:			
B1.	Proximity to Groundwater Discharge Zone	>20 km (1)	5 - 20 km (3)	0 - 5 km (5)
B2.	Injection Formation(s) continuity/Area Extent	3 Continuous (1)	2 Continuous (3)	1 Continuous (5)
B3.	Containment Capabilities/Integrity of Confining Layer(s)	High (1)	Intermediate (3)	Low (5)
C.	Resource Information:			
C1.	Proximity to Existing or Proposed Injection Wells	>20 km (1)	5 - 20 km (3)	0 - 5 km (5)
C2.	Existence of Potentially Usable Oil and Gas Wells for Monitoring Testing Purposes	No. (1)	-----	Yes (5)
C3.	Number of Injection Formations being used in Township	Zero (1)	One (3)	Two or Three (5)
C4.	Volumetric Injection Rate	0 - 20 m^3/hr (1)	20 - 100 m^3/hr (3)	>100 m^3 (3)

---

* High weight number - higher ranking

TABLE 11
NEW SITES FOR MONITORING WELLS

Township	Range	Section	Number of Injection Wells
Area 2			
55	6	3	0
55	6	4	0
55	6	5	0
55	6	8	0
55	6	9	1
55	6	10	0
55	6	11	0
55	6	12	0
55	6	13	1
55	6	14	0
55	6	15	0
55	6	16	0
55	6	17	0
55	6	20	0
55	6	21	0
55	6	22	0
55	6	23	0
55	6	24	0
55	6	25	0
55	6	26	0
55	6	27	0
55	6	28	2
55	6	29	0
55	6	32	0
55	6	33	0
55	6	34	0
56	6	1	0
56	6	3	1
56	6	4	0
56	6	5	0
56	6	9	0
56	6	10	0
56	6	11	0
Area 4			
58	4	18	1
58	4	30	0
59	4	8	0

TABLE 11 (Concluded)

Township	Range	Section	Number of Injection Wells
Area 6			
61	4	17	0
61	4	18	0
61	4	19	1
61	4	20	0
61	4	21	0
61	4	22	0
61	4	28	4
61	4	29	0
61	4	30	0
61	4	32	0
61	4	33	0
61	4	34	0
Area 7			
64	3	15	0
64	3	22	2
64	3	27	0
64	3	28	0
64	3	30	0
65	2	10	0
65	2	11	0
65	2	12	0
65	2	13	0
65	2	14	1
65	2	15	0
65	2	23	0
65	2	24	0
Area 10			
66	5	6	0
66	5	7	1
66	5	18	0

7.0 CONCLUSIONS

1. Existing Pressure - Volume Data

The evaluation of pressure-volume data (ERCB) from 60 waste injection wells in the study area concluded that the ERCB information, consisting of monthly maximum well head pressure, volume injected and hours of injection, is of no use in establishing a pressure-volume relationship.

Six waste injection wells with a minimum of seven years of monthly injection data were selected to evaluate their respective daily injection data. Like the monthly data the data also show relatively constant well head pressure regardless of injected volumes. SAEL concludes that the data can not be used to validate the predicted pressures simulated by the ARC model.

2. Waste Injection Well; Swan Hills, Alberta

At the interim meeting, it was proposed by Alberta Environment that the Swan Hills injection well be modelled because daily injection data were available. An examination of the injection data also indicated injection was conducted on the "as needed basis", similar to industry, but good daily injection data were available for modelling purposes.

Two sets of injection data from the waste injection well at the Alberta Special Waste Facility from April 24 to June 29, 1988 and October 18 to November 30, 1988 were chosen to evaluate the ARC model.

3. ARC Computer Modelling, Basin Analysis Group

Bottomhole pressures simulated at the waste injection well at Swan Hills, using high hydraulic characteristics (permeability and storativity) were similar to the measured pressures. The simulated pressures were generally 0.5 to 9 percent higher than the measured pressures which were typically 14,500 to 15,000 kPa. Though the simulated pressures were slightly higher than the measured pressures, model calibration and the recording of more reliable and accurate injection data could result in lower simulated pressures which would be representative of the measured pressures.

4. Existing Wells

The study considered existing hydrocarbon gas and oil wells and observation wells. The use of existing hydrocarbon wells would be difficult as the majority of these wells are being used for hydrocarbon production. If an existing well does become available, it would have to be recompleted in the zone of interest by perforating the casing which may have a number of implications regarding geochemical sampling and hydraulic testing. Unless a detailed history of the well is available for type of drilling muds, hydraulic fracturing, geochemical treatments, production history etc., the reliability of data collected from the well could be questioned.

Based on the well listing in the PIX cards and the ERCB, forty-six observation wells exist in the high preference area 7. Since these wells are used for observation purposes and penetrate a waste injection zone, these wells appear to be the most suitable candidates for monitoring the impact of waste injection in the Mannville Group waste disposal unit.

None of the existing potential monitoring wells listed in the PIX cards and ERCB penetrate the Deadwood/Granite Wash disposal unit.

The ERCB computer file provides a large data base and information on each well (Appendix E). The problem is that this data base is only available to the public via the computer at the Calgary ERCB office.

5. New Monitoring Site

Based on modelling by the Basin Analysis Group, specific areas for the installation of new monitoring wells were delineated using the Intera criteria and data collected during the study.

8.0 RECOMMENDATIONS

1. Set standards on how well injection data are measured and recorded. This would include:
    - a) elevation of recorder,
    - b) injection rates and operating time,
    - c) the calculation and reporting of subsurface pressures,

    Industry should use a consistant methodology, so the injection well data can be evaluated over the long-term operation of these injection wells. Daily injection data are recommended.

2. Work with the oil companies, especially the ones with observation wells in the high preference areas to determine the potential of installing pressure recorders in these wells to monitor subsurface pressures.

3. Additional and detailed information on existing wells is available on the ERCB computer. It is recommended that the NHRI enquire on the use of this data base in its search for a potential monitoring well.

9.0 REFERENCES

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APPENDIX A

WASTE INJECTION WELL DATA

LIST OF INJECTION WELLS

NO.	WELL NAME	WELL LOCATION	WELL ID	COMPANY NAME	DISPOSAL FORMATION	PERFORATED INTERVAL (m KB)	YEARS OF MONTHLY WATER PRODUCTION RECORDS		
							INJECTION VOLUME	HOURS	PRESSURE
1	WESTMIN LINDBERGH	11-1-55-5 W4M	00/11-1-55-5 W4/2	WESTMIN RESOURCES LTD.	LLOYDMINISTER	517-529	5	5	0
2	DOME ET AL LINDBERGH	10D-18-55-5 W4M	00/10-18-55-5 4W/0	DOME PETROLEUM LTD.	REX SAND	540-545	6	6	5
3	BRASCAN LINDBERGH	6-27-55-5 W4M	B0/6-27-55-5 W4/2	WESTMIN RESOURCES LTD.	LLOYDMINISTER	532-536	4	4	0
4	DOME ET AL LINDBERGH	3A-30-55-5 W4M	00/3-30-55-5W4/0	DOME PETROLEUM LTD.	REX	604(TD)	6	6	5
5	PCP LINDBERGH	10-9-55-6 W4M	00/10-9-55-6W4/2	PANCANADIAN PETROLEUM LTD.	LLOYDMINISTER	553-568	5	5	5
6	WESTMIN LINDBERGH	3-13-55-6 W4M	00/3-13-55-6 W4/0	WESTMIN RESOURCES LTD.	COOKING LAKE	665-708	3	3	0
7	DOME LINDBERGH	11-24-55-6 W4M	02/11-24-55-6 W4/0	DOME PETROLEUM LTD.	---	703(TD)	2	2	2
8	AMOCO B-31 LINDBERGH	7-28-55-6 W4M	00/7-28-55-6 W4/2	AMOCO CANADA LTD.	---	740(TD)	2	2	1
9	AMOCO SWD LINDBERGH	9-28-55-6 W4M	02/9-28-55-6 W4/2	AMOCO CANADA LTD.	LLOYDMINISTER	552-565	3	3	3
10	MINERALS HAIRY	7-22-55-14 W4M	00/7-22-55-14 W4/2	WESTMIN RESOURCES LTD.	NISKU	652-649	11	11	2
11	IMPERIAL WILLINGDON NO. 1	14-14-55-15 W4M	00/14-14-55-15 W4/0	WILLINGDON	LLOYDMINISTER	657-659	6	6	0
12	HB JOHN LAKE	5-12-56-1 W4M	00/6-12-56-1 W4/0	HUDSON'S BAY OIL AND GAS	CALMUT MEM.	704-714	4	4	0
13	ELK POINT NO. 7	7-25-56-5 W4M	00/7-25-56-5 W4/0	CANADIAN SALT CO.	LINDBERGH SPARKY	416-417	16	15	0
14	PCP LINDBERGH	6-3-56-6 W4M	02/6-3-56-6- W4/0	PANCANADIAN PETROLEUM LTD.	LLOYDMINISTER	555-575	2	2	2
15	MERLAND BRASCAN UKALTA	12-31-56-17 W4M	00/12-31-56-17 W4/0	MERLAND EXPLORATION LTD.	GLAUCONITIC SANDSTONE	730-731	7	7	2
16	CANOXY LINDBERGH	5-18-58-4 W4M	02/5-18-58-4 W4/0	CANADIAN OCCIDENTAL LTD	COOKING LAKE	604-614	2	2	2
17	MURPHY SWD FWD 2 LINDBERGH	5-13-58-5 W4M	02/5-13-58-5 W4/0	MURPHY OIL CO.	COOKING LAKE	578-615	9	9	0
18	BOCO ET AL LINDBERGH	4-14-58-5 W4M	00/4-14-58-5 W4/0	MURPHY OIL CO.	GRANDE RAPIDS	511-515	6	6	0
19	FINA CACHE	10-18-58-11 W4M	00/10-18-58-11 W4/2	DOME PETROLEUM LTD.	SPARKY	521-525	10	10	10
20	CWNE MURIEL LK	10-16-59-4 W4M	00/10-16-59-4 W4/0	CANADIAN WORLDWIDE LTD.	CUMMINGS	504-510	2	2	0
[illegible]1	BRENDA	2-4-60-13 W4M	00/2-4-60-13 W4/0	BRENDA MINES		683(TD)	9	9	7
22	BP BGUL BELLIS	12-4-60-15 W4M	02/12-4-60-15 W4/0	BP RESOURCES CANADA	CAMROSE	661-671	9	9	7

LIST OF INJECTION WELLS(continued)

NO.	WELL NAME	WELL LOCATION	WELL ID	COMPANY NAME	DISPOSAL FORMATION	PERFORATED INTERVAL (m KB)	YEARS OF MONTHLY WATER PRODUCTION RECORDS		
							INJECTION VOLUME	HOURS	PRESSURE
23	SOBC BEAVER CROSSING	8-36-61-2 W4M	00/8-36-61-2 W4/0	CHEVERON CANADA RESOURCES LTD.	CLEARWATER	407-421	8	8	8
24	CCL BEAVER CROSSING SWD	16-36-61-2 W4M	02/16-36-61-2 W4/0	CHEVERON CANADA RESOURCES LTD.	CLEARWATER	414-442	8	8	8
25	KOCH SWD FT. KENT	6-19-61-4 W4M	00/6-19-61-4 W4/2	KOCH EXPLORATION LTD.	CLEARWATER	454-483	3	3	0
26	SUNCOR CWWE FT. KENT	2-28-61-4 W4M	02/2-28-61-4 W4/0	SUNCOR INC.	CUMMINGS	412-457	5	5	5
27	SUNCOR CWWE FT. KENT	5A-28-61-4 W4M	A2/5-28-61-4 W4/2	SUNCOR INC.	CLEARWATER	444-452	12	12	12
28	SUNCOR CWWE FT. KENT	5A-28-61-4 W4M	A2/5-28-61-4 W4/0	SUNCOR INC.	CUMMINGS	500-503			
29	SUNCOR CWWE FT. KENT	5-28-61-4 W4M	03/5-28-61-4 W4/0	SUNCOR INC.	CLEARWATER	450-480	-		1
30	PROVIDENT HANMORE	6-1-61-17 W4M	00/6-1-61-17 W4/0	SCEPTRE RESOURCES LTD.	GLAUCONITIC SANDSTONE	644-649	11	11	5
31	UTEXCAN	13-20-62-3 W4M	AA/13-20-62-3 W4/0	EXCEL ENERGY		482(TD)	2	2	2
32	CDNOXY	12-01-63-8 W4M	AA/12-01-63-8 W4/0	CANADIAN OCCIDENT PETROLEUM LTD.	---	490(TD)			
33	AMOCO ET AL WDW-2 SUGDEN	2-3-63-8 W4M	00/2-3-63-8 W4/0	AMOCO CANADA PETROLEUM LTD.	CUMMINGS SAND	409-413			
34	AMOCO ET AL WDW-1 SUGDEN	6-4-63-8 W4M	02/6-4-63-8 W4/0	AMOCO CANADA PETROLEUM LTD.	CUMMINGS SAND	409-413	2	2	2
35	WESTCOAST MANATOKAN	10-12-63-8 W4M	00/10-12-63-8 W4/0	CANADIAN OCCIDENT PETROLEUM LTD.	COOKING LAKE	488-497	6	6	6
36	CDNOXY ET AL SWD	6-13-63-8 W4M	00/6-13-63-8 W4/2	CANADIAN OCCIDENT PETROLEUM LTD.	COOKING LAKE	508-530	2	2	2
37	CDNOXY	6-13-63-8 W4M	02/6-13-63-8 W4/0	CANADIAN OCCIDENT PETROLEUM LTD.	CAMBRIAN	1462(TD)	1	1	1
38	CDNOXY	8-24-63-8 W4M	00/8-24-63-8- W4/0	CANADIAN OCCIDENT PETROLEUM LTD.	---	520(TD)			
39	WINCAN ET AL CRAIGEND	11-33-63-[illegible]4M	00/11-33-63-11 W4/0	WINTERSHALL	---	541(TD)	2	2	2
40	ESSO 79 SWD COLDLK	7-18-64-3 W4M	00/7-18-64-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1248-1268	3	3	3
41	ESSO 85 SWD ETHELLK	1-19-64-3 W4M	00/1-19-64-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1245-1288	3	3	3
42	ESSO ETHELLK SWD	10-22-64-3 W4M	02/10-22-64-3 W4/0	ESSO RESOURCES CANADA LTD.	---	562(TD)	5	5	5

LIST OF INJECTION WELLS(continued)

NO.	WELL NAME	WELL LOCATION	WELL ID	COMPANY NAME	DISPOSAL [illegible]	PERFORATED INTERVAL (m KB)	YEARS OF MONTHLY WATER PRODUCTION RECORDS		
							INJECTION VOLUME	HOURS	PRESSURE
43	ESSO 83 SWD ETHELLK	11-22-64-3 W4M	00/11-22-64-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1262-1282	1	1	1
44	ESSO 81 SWD ETHELLK	3-29-64-3 W4M	00/03-29-64-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1264-1284	1	1	1
45	ESSO 83 SWD ETHELLK	1-32-64-3 W4M	00/1-32-64-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1308-1328	4	4	4
46	ESSO 83 INJ ETHLLK	8-33-64-3 W4M	00/8-33-64-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1281-1301	4	4	4
47	HUSKY TUCKER LAKE	13A-20-64-4 W4M	00/13-20-64-4 W4/0	HUSKY OIL OPERATIONS LTD.	MCMURRAY	535-547	4	4	0
48	MOBIL GARTH	6-11-64-6 W4M	00/6-11-64-6 W4/0	MOBIL OIL CANADA LTD.	CLEARWATER	439-447	3	3	3
49	MOBIL GARTH	12-6-64-6 W4M	00/12-6-64-6 W4/0	MOBIL OIL CANADA LTD.	CAMBRIAN	1279-1299	3	3	3
[illegible]	PUBCO CRAIGEND	10-1-64-13 W4M	00/10-1-64-13 W4/2	DOME PETROLEUM LTD.	LOWER GRAND RAPIDS	433-439	7	7	2
51	SUPTST NUL CIGOL	10-25-64-14 W4M	00/10-25-64-14 W4/0	BP RESOURCES LTD	GROSSMONT A	488-491	7	7	0
52	MANVILLE ET AL FIGURE	2-30-64-16 W4M	00/2-30-64-16 W4/0	MANVILLE OIL & GAS	NISKU	590-595	2	2	1
53	GULF COLD LAKE	1-14-65-2 W4M	00/1-14-65-2 W4/0	BOW VALLEY INDUSTRIES	MCMURRAY	517-562	5	5	5
54	ESSO 83 SWD ETHELLK	2-3-65-3 W4M	02/2-3-65-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1270-1289			
55	ESSO SWD LEMING	3-4-65-3 W4M	00/3-4-65-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1270-1290	5	5	5
56	IMP73	[illegible]	AH/14-5-65-3 W4/0	ESSO RESOURCES CANADA LTD.	---	546(TD)			
57	IMP73	14-5-65-3 W4M	AJ/14-5-65-3 W4/0	ESSO RESOURCES CANADA LTD.	---	553(TD)			
58	ESSO 78 INJ ETHELLK	11-7-65-3 W4M	00/11-7-65-3 W4/0	ESSO RESOURCES CANADA LTD.	MCMURRAY	518-530	6	6	6
59	ESSO 79 SWD ETHELLK	12-8-65-3 W4M	00/12-8-65-3 W4/0	ESSO RESOURCES CANADA LTD.	CAMBRIAN	1240-1260	6	6	6
60	ESSO 78 INJ ETHELLK	4-17-65-3 W4M	00/4-17-65-3 W4/0	ESSO RESOURCES CANADA LTD.	MCMURRAY	509-521	9	9	9

LIST OF INJECTION WELLS

NO.	WELL NAME	WELL LOCATION	WELL ID	COMPANY NAME	DISPOSAL FORMATION	PERFORATED INTERVAL (m KB)	YEARS OF MONTHLY WATER PRODUCTION RECORDS		
							INJECTION VOLUME	HOURS	PRESSURE
61	BP MARGLK WDW-1	8-7-66-5 W4M	AB/8-7-66-5 W4/0	BP RESOURCES CANADA LTD	GRAND RAPIDS	422-436	3	3	[illegible]
62	BP WDW PCI LEMING	05-8-66-5 W4M	00/5-8-66-5 W4/0	BP RESOURCES CANADA LTD.	CAMBRIAN	1358(TD)	2	2	3
63	BP PCI MARG LK	9-8-66-5 W4M	00/9-8-66-5 W4/0	BP RESOURCES CANADA LTD.	CAMBRIAN	1266-1334			
64	BP PCI MARG LK	10-8-66-5 W4M	00/10-8-66-5 W4/0	BP RESOURCES CANADA LTD.	CAMBRIAN	1318-1334	3	3	3
65	BVI LAC LA BICHE	11-19-66-3 W4M	00/11-19-66-3 W4/0	BOW VALLEY INDUSTRIES	GROSMONT A	483-488	4	4	[illegible]
66	DOME AEC 10B4 MOORE	10-5-67-4 W4M	02/10-5-67-4 W4/0	DOME PETROLEUM LTD.	CAMBRIAN	1304-1320	3	3	3
67	DOME AEC 10D4 MOORE	10-5-67-4 W4M	03/10-5-67-4 W4/0	DOME PETROLEUM LTD.	MCMURRAY	539-543	4	4	
68	GEOG ET AL HYLO	6-3-67-14 W4M	00/6-3-67-14 W4M	ULTRAMAR OIL & GAS OF CANADA LTD	GROSMONT	521-522	7	7	0
69	GLOBAL	2-3-67-16 W4M	00/2-3-67-16 W4/0	THOMSON		547(TD)			
70	NOVALTA UNIT SWD	11-3-69-16 W4M	00/11-3-69-16 W4/2	NOVALTA RESOURCES	GROSSMONT	489-492			
71	BP ATMORE	11-21-67-17 W4M	00/11-21-67-17 W4/2	BP RESOURCES CANADA LTD.	NISKU	534-548			

YEARS OF INJECTION VOLUME AND PRESSURE

RECORD NO.	WELL NAME	WELL LOCATION	COMPANY NAME	DISPOSAL FORMATION	YEARS OF MONTHLY WATER PRODUCTION RECORDS	
					INJECTION VOLUME	PRESSURE
27	SUNCOR CWWE FT. KENT	5A-28-61-4 W4M	SUNCOR INC.	CLEARWATER	12	12
19	FINA CACHE	10-18-58-11 W4M	DOME PETROLEUM	SPARKY	10	10
61	ESSO 78 INJ ETHELLK	4-17-65-3 W4M	ESSO RESOURCES	MCMURRAY	9	9
23	GOBC BEAVER CROSSING	8-36-61-2 W4M	CHEVERON CANADA	CLEARWATER	8	8
24	CCL BEAVER CROSSING	16-36-61-2 W4M	CHEVERON CANADA	CLEARWATER	8	8
22	BP BGUL BELLIS	12-4-60-15 W4M	BP RESOURCES	CAMROSE	9	7
21	BRENDA	2-4-60-13 W4M	BRENDA MINES		9	7
58	ESSO 78 INJ ETHELLK	11-7-65-3 W4M	ESSO RESOURCES	MCMURRAY	6	6
35	WESTCOAST MANATOKAN	10-12-63-8 W4M	CANADIAN OCCIDENTAL	COOKING LAKE	6	6
59	ESSO 79 SWD ETHELLK	12-8-65-3 W4M	ESSO RESOURCES	CAMBRIAN	6	6
30	PROVIDENT HANMORE	6-1-61-17 W4M	SCEPTRE RESOURCES	GLAUCONITIC	11	5
2	DOME ET AL LINDBERGH	10D-18-55-5 W4M	DOME PETROLEUM	REX SAND	6	5
4	DOME ET AL LINDBERGH	3A-30-55-5 W4M	DOME PETROLEUM	REX	6	5
5	PCP LINDBERGH	10-9-55-6 W4M	PANCANADIAN	LLOYDMINISTER	5	5
42	ESSO ETHELLK SWD	10-22-64-3 W4M	ESSO RESOURCES	---	5	5
[illegible]	[illegible] FT. KENT	2-28-61-4 W4M	SUNCOR INC.	CUMMINGS	5	5
53	GULF COLD LAKE	1-14-65-2 W4M	BOW VALLEY	MCMURRAY	5	5
55	ESSO SWD LEMING	3-4-65-3 W4M	ESSO RESOURCES	CAMBRIAN	5	5
45	ESSO 83 SWD ETHELLK	1-32-64-3 W4M	ESSO RESOURCES	CAMBRIAN	4	4
67	DOME AEC 10D4 MOORE	10-5-67-4 W4M	DOME PETROLEUM	MCMURRAY	4	4
46	ESSO 83 INJ ETHLLK	8-33-64-3 W4M	ESSO RESOURCES	CAMBRIAN	4	4
10	MINERALS HAIRY	7-22-55-14 W4M	WESTMIN	NISKU	11	3
48	MOBIL GARTH	6-11-64-6 W4M	MOBIL OIL	CLEARWATER	3	3
9	AMOCO SWD LINDBERGH	9-28-55-6 W4M	AMOCO CANADA	LLOYDMINISTER	3	3
40	ESSO 79 SWD COLDLK	7-18-64-3 W4M	ESSO RESOURCES	CAMBRIAN	3	3
49	MOBIL GARTH	12-6-64-6 W4M	MOBIL OIL	CAMBRIAN	3	3
66	DOME AEC 10B4 MOORE	10-5-67-4 W4M	DOME PETROLEUM	CAMBRIAN	3	3
41	ESSO 85 SWD ETHELLK	1-19-64-3 W4M	ESSO RESOURCES	CAMBRIAN	3	3
64	BP PCI MARG LK	10-6-66-5 W4M	BP RESOURCES	CAMBRIAN	3	3
50	PUGCO CRAIGEND	10-1-64-13 W4M	DOME PETROLEUM	LOWER GRAND	7	2
15	MERLAND BRASCAN	12-31-56-17 W4M	MERLAND	GLAUCONITIC	7	2
14	PCP LINDBERGH	6-3-56-6- W4M	PANCANADIAN	LLOYDMINISTER	2	2
39	WINCAN ET AL	11-33-63-11 W4M	WINTERSHALL	---	2	2
36	CDNOXY ET AL SWD	6-13-63-8 W4M	CANADIAN OCCIDENTAL	COOKING LAKE	2	2
7	DOME LINDBERGH	11-24-55-6 W4M	DOME PETROLEUM	---	2	2
34	AMOCO ET AL WDW-1	6-4-63-8 W4M	AMOCO CANADA	CUMMINGS SAND	2	2
31	UTEXCAN	13-20-62-3 W4M	EXCEL ENERGY		2	2
16	CANOXY LINDBERGH	5-18-58-4 W4M	CANADIAN	COOKING LAKE	2	2
61	BP MARGLK WDW-1	8-7-66-5 W4M	BP RESOURCES	GRAND RAPIDS	9	1
65	BVI LAC LA BICHE	11-19-66-3 W4M	BOW VALLEY	GROSMONT A	4	1
52	MANVILLE ET AL	2-30-64-16 W4M	MANVILLE OIL &	NISKU	2	1
8	AMOCO B-31 LINDBERGH	7-28-55-6 W4M	AMOCO CANADA	---	2	1
29	SUNCOR CWWE FT. KENT	5-28-61-4 W4M	SUNCOR INC.	CLEARWATER	1	1
3	BRASCAN LINDBERGH	6-27-55-5 W4M	WESTMIN	LLOYDMINISTER	4	0

YEARS OF INJECTION VOLUME AND PRESSURE

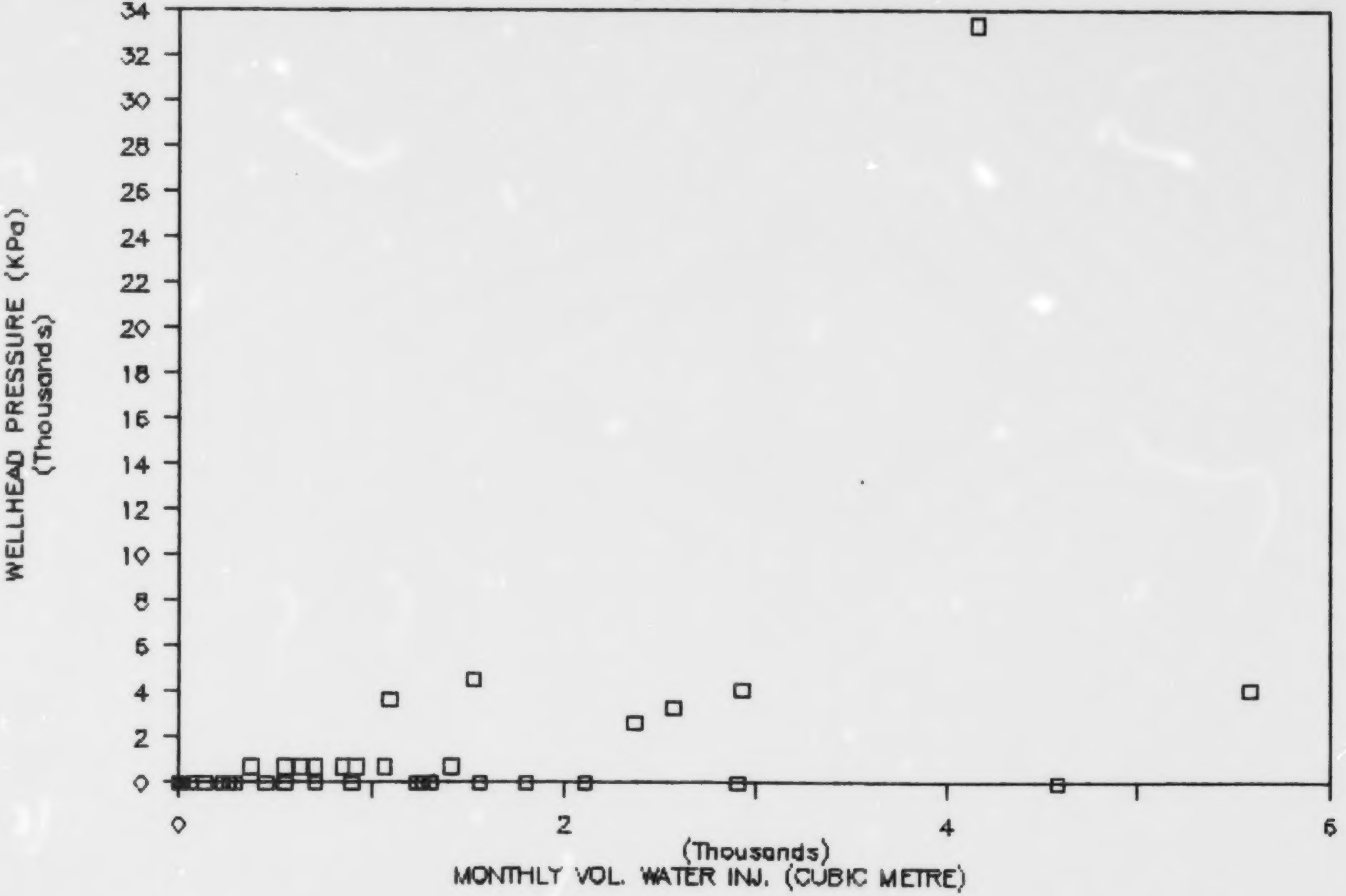
RECORD NO.	WELL NAME	WELL LOCATION	COMPANY NAME	DISPOSAL FORMATION	YEARS OF MONTHLY WATER PRODUCTION RECORDS	
					INJECTION VOLUME	PRESSURE
43	ESSO 83 SWD ETHELLK	11-22-64-3 W4M	ESSO RESOURCES	CAMBRIAN	1	1
44	ESSO 81 SWD ETHELLK	3-29-64-3 W4M	ESSO RESOURCES	CAMBRIAN	1	1
37	CDNOXY	6-13-63-8 W4M	CANADIAN OCCIDENTAL	CAMBRIAN	1	1
13	ELK POINT NO. 7	7-25-56-5 W4M	CANADIAN SALT	LINDBERGH	16	0
17	MURPHY SWD FWD 2	5-13-58-5 W4M	MURPHY OIL CO.	COOKING LAKE	9	0
68	GEOG ET AL HYLO	6-3-67-14 W4M	ULTRAMAR OIL &	GROSMONT	7	0
51	SUPTST NUL CIGOL	10-25-64-14 W4M	BP RESOURCES LTD	GROSSMONT A	7	0
18	BOCO ET AL	4-14-58-5 W4M	MURPHY OIL CO.	GRANDE RAPIDS	6	0
11	IMPERIAL WILLINGDON	14-14-55-15 W4M	WILLINGDON	LLOYDMINISTER	6	0
1	WESTMIN LINDBERGH	11-1-55-5 W4M	WESTMIN	LLOYDMINISTER	5	0
47	HUSKY TUCKER LAKE	13A-20-64-4 W4M	HUSKY OIL	MCMURRAY	4	0
12	HB JOHN LAKE	6-12-56-1 W4M	HUDSON'S BAY	CALMUT MEM.	4	0
25	KOCH SWD FT. KENT	6-19-61-4 W4M	KOCH EXPLORATION	CLEARWATER	3	0
6	WESTMIN LINDBERGH	3-13-55-6 W4M	WESTMIN	COOKING LAKE	3	0
20	CWWE MURIEL LK	10-16-59-4 W4M	CANADIAN	CUMMINGS	2	0
62	BP WDW PCI LEMING	05-8-66-5 W4M	BP RESOURCES	CAMBRIAN	2	0
54	ESSO 83 SWD ETHELLK	2-3-65-3 W4M	ESSO RESOURCES	CAMBRIAN		
63	BP PCI MARG LK	9-8-66-5 W4M	BP RESOURCES	CAMBRIAN		
28	SUNCOR CWWE FT. KENT	5A-28-61-4 W4M	SUNCOR INC.	CUMMINGS		
56	IMP73	14-5-65-3 W4M	ESSO RESOURCES	---		
60	ESSO 79 SWD ETHELLK	12-8-65-3 W4M	ESSO RESOURCES	CAMBRIAN		
69	GLOBAL	2-3-67-16 W4M	THOMSON			
57	IMP73	14-5-65-3 W4M	ESSO RESOURCES	---		
71	BP ATMORE	11-21-67-17 W4M	BP RESOURCES	NISKU		
33	AMOCO ET AL WDW-2	2-3-63-8 W4M	AMOCO CANADA	CUMMINGS SAND		
32	CDNOXY	12-01-63-8 W4M	CANADIAN OCCIDENTAL	---		
70	NOVALTA UNIT SWD	11-3-69-16 W4M	NOVALTA RESOURCES	GROSSMONT		
38	CDNOXY	8-24-63-8 W4M	CANADIAN OCCIDENTAL	---		

APPENDIX B

GRAPHICAL PLOTS
PRESSURE - VOLUME RELATIONSHIP

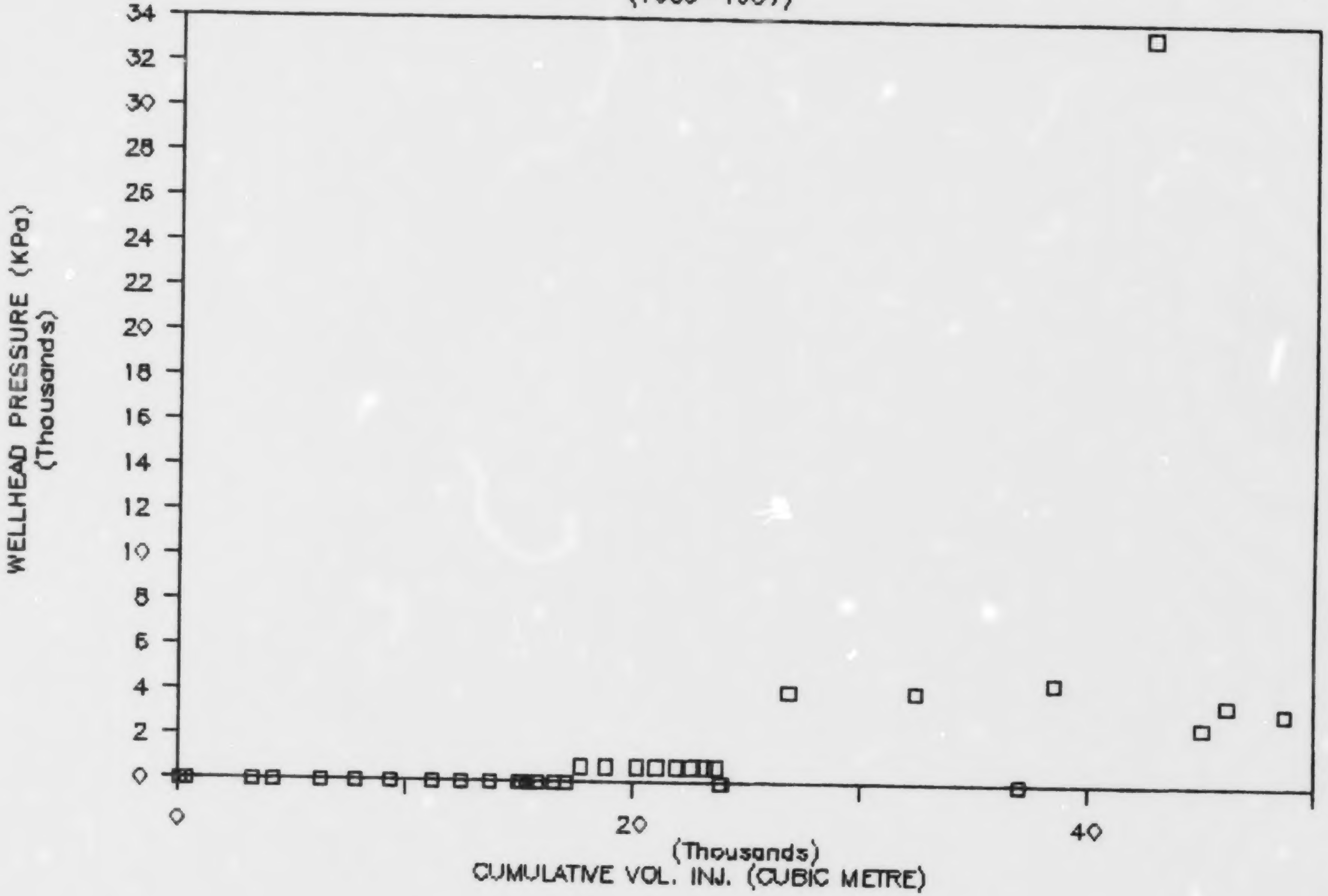
DOME ET AL LINDBERGH 3A-30-55-5 W4M

(1983-1987)



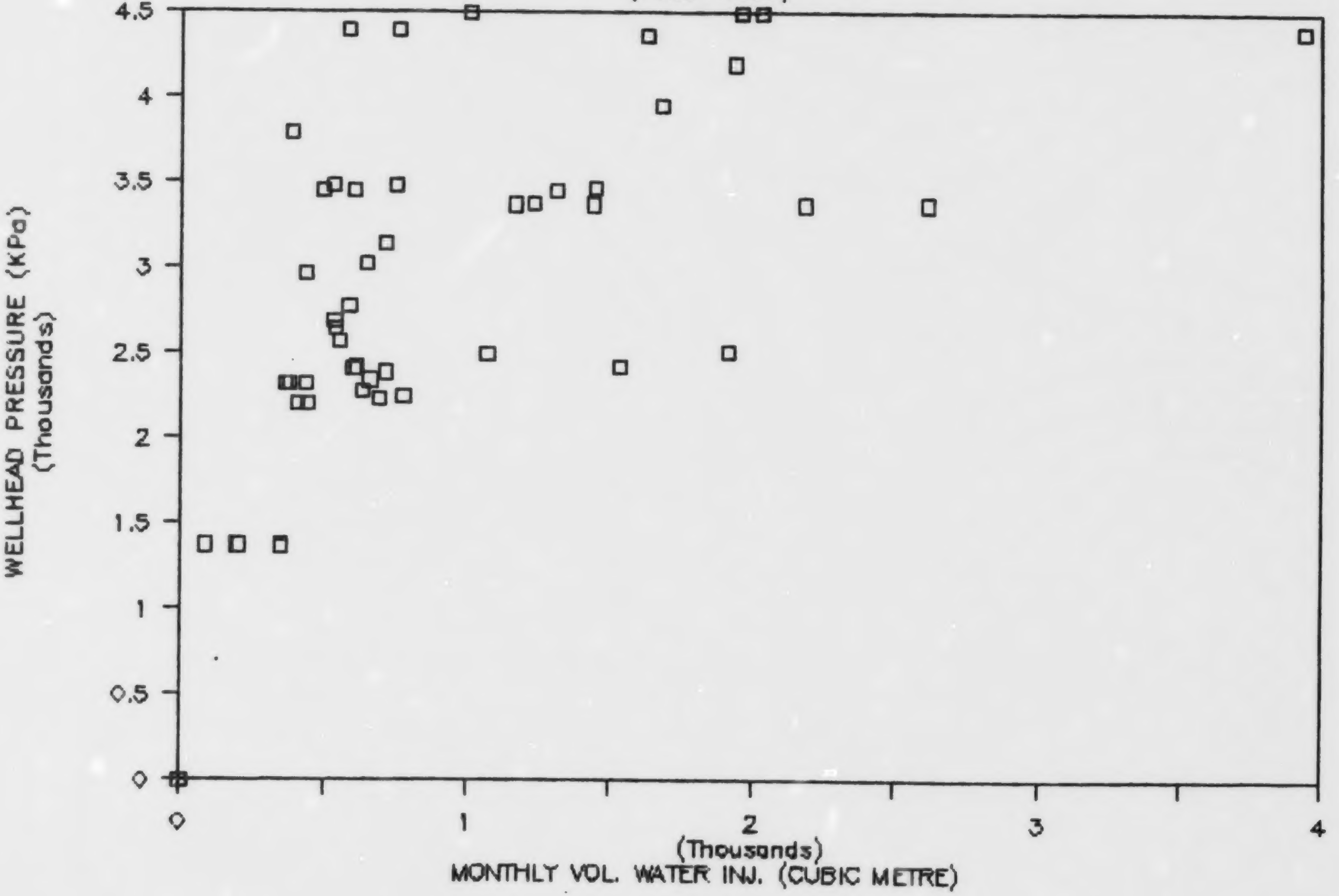
DOME ET AL LINDBERGH 3A-30-55-5 W4M

(1983-1987)



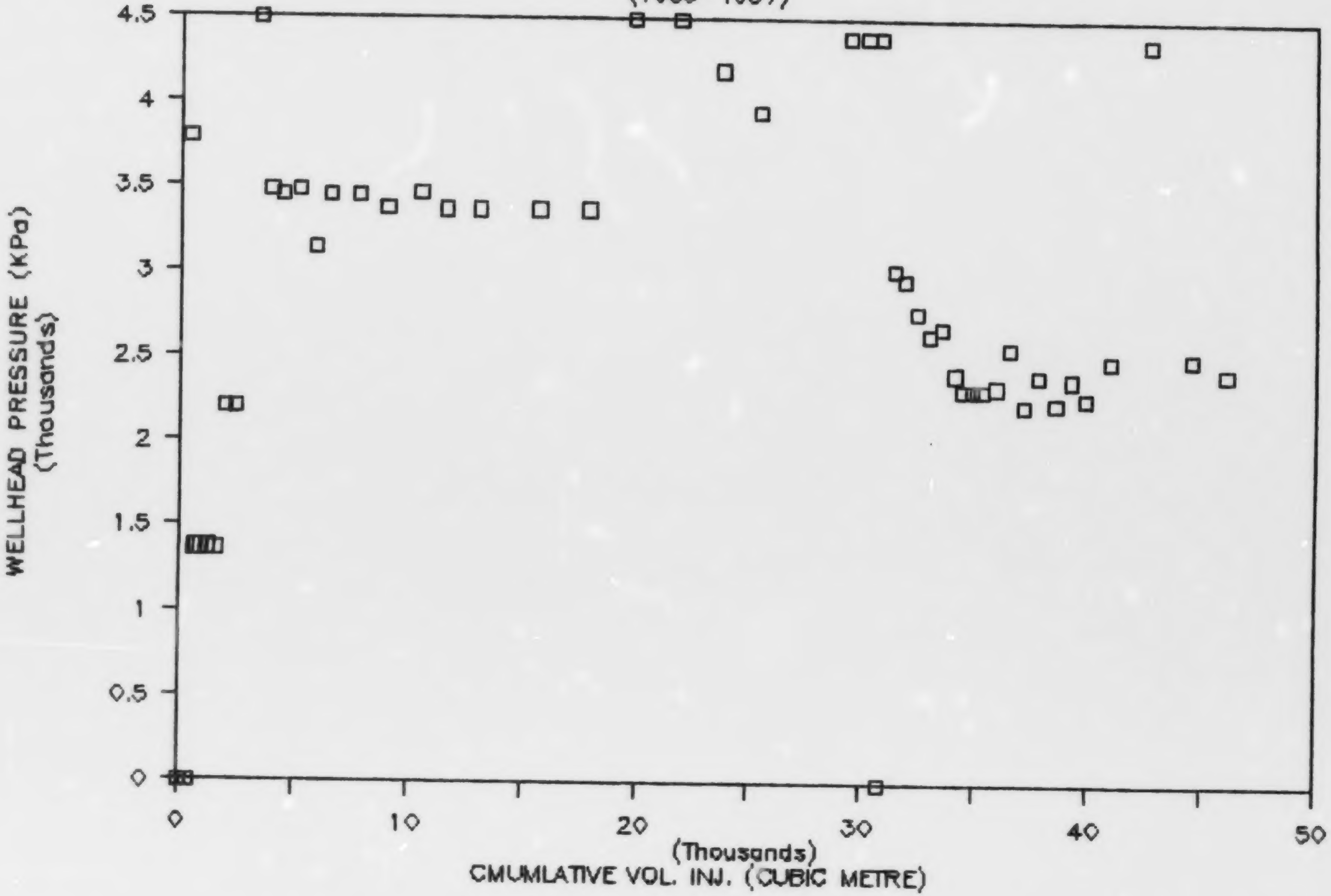
PCP LINDBERGH 10A-9-55-6 W4M

(1983–1987)



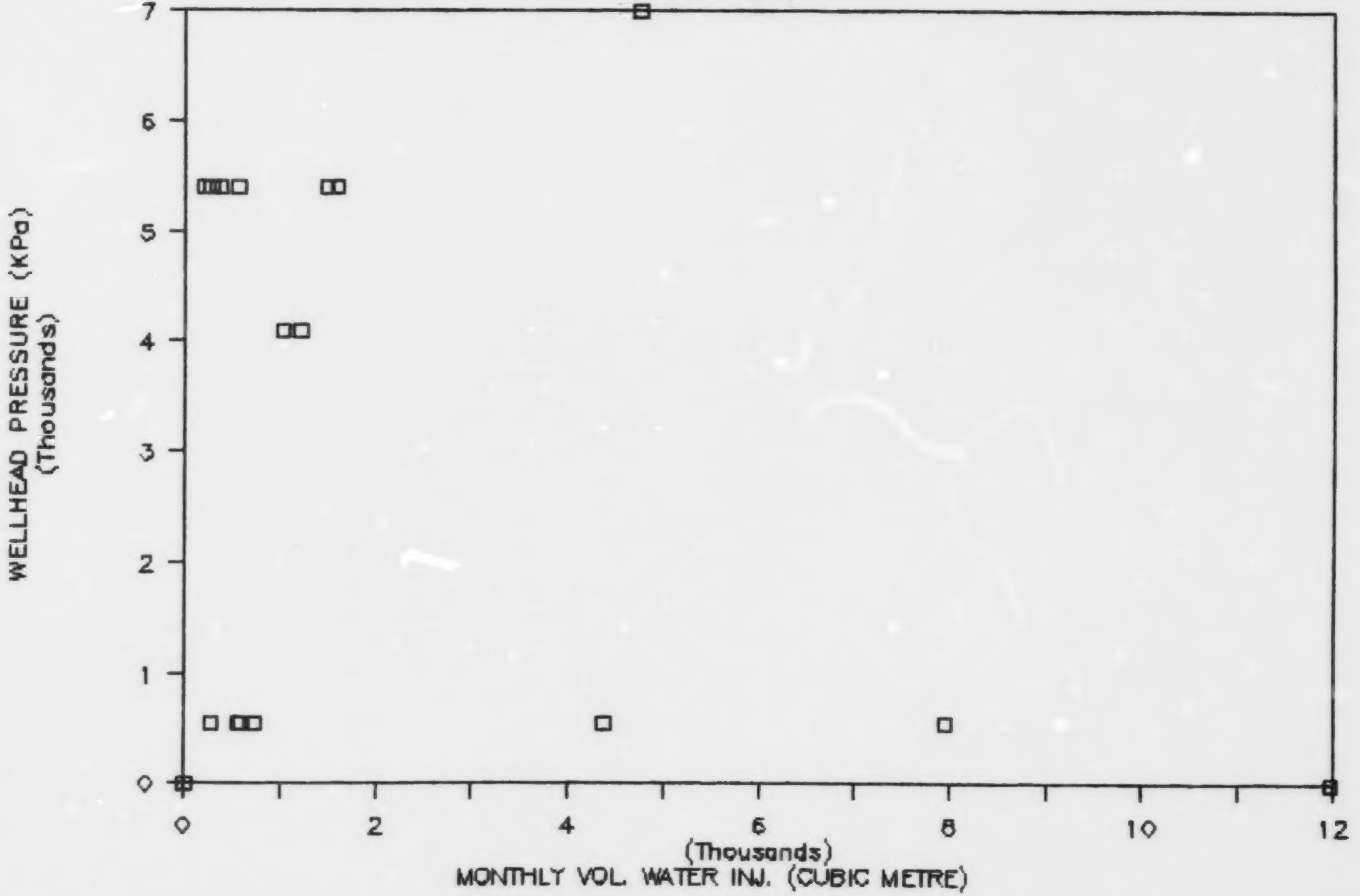
PCP LINDBERGH 10A-9-55-6 W4M

(1983-1987)



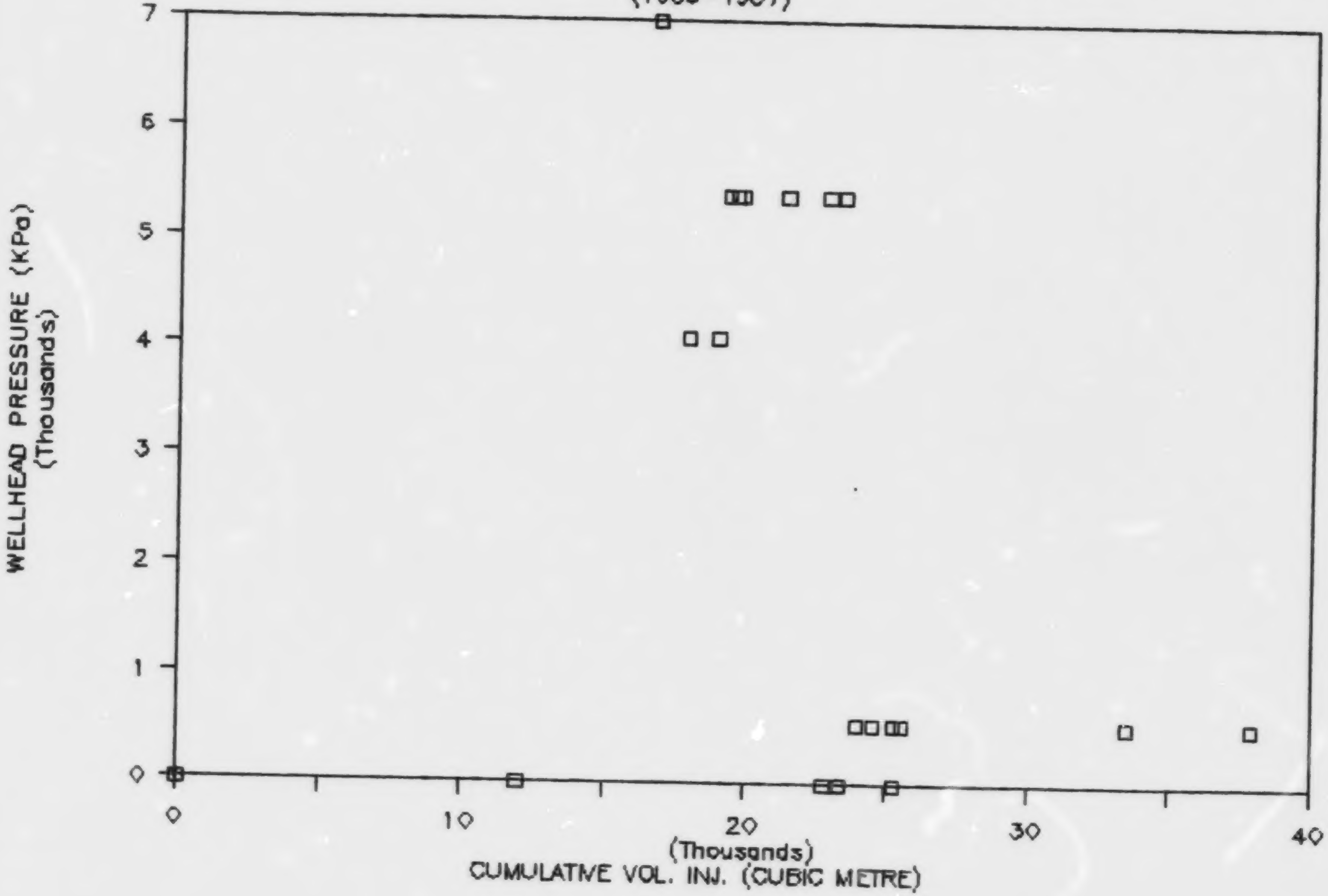
DOME ET AL LINDBERGH 11-24-55-6 W4M

(1986-1987)



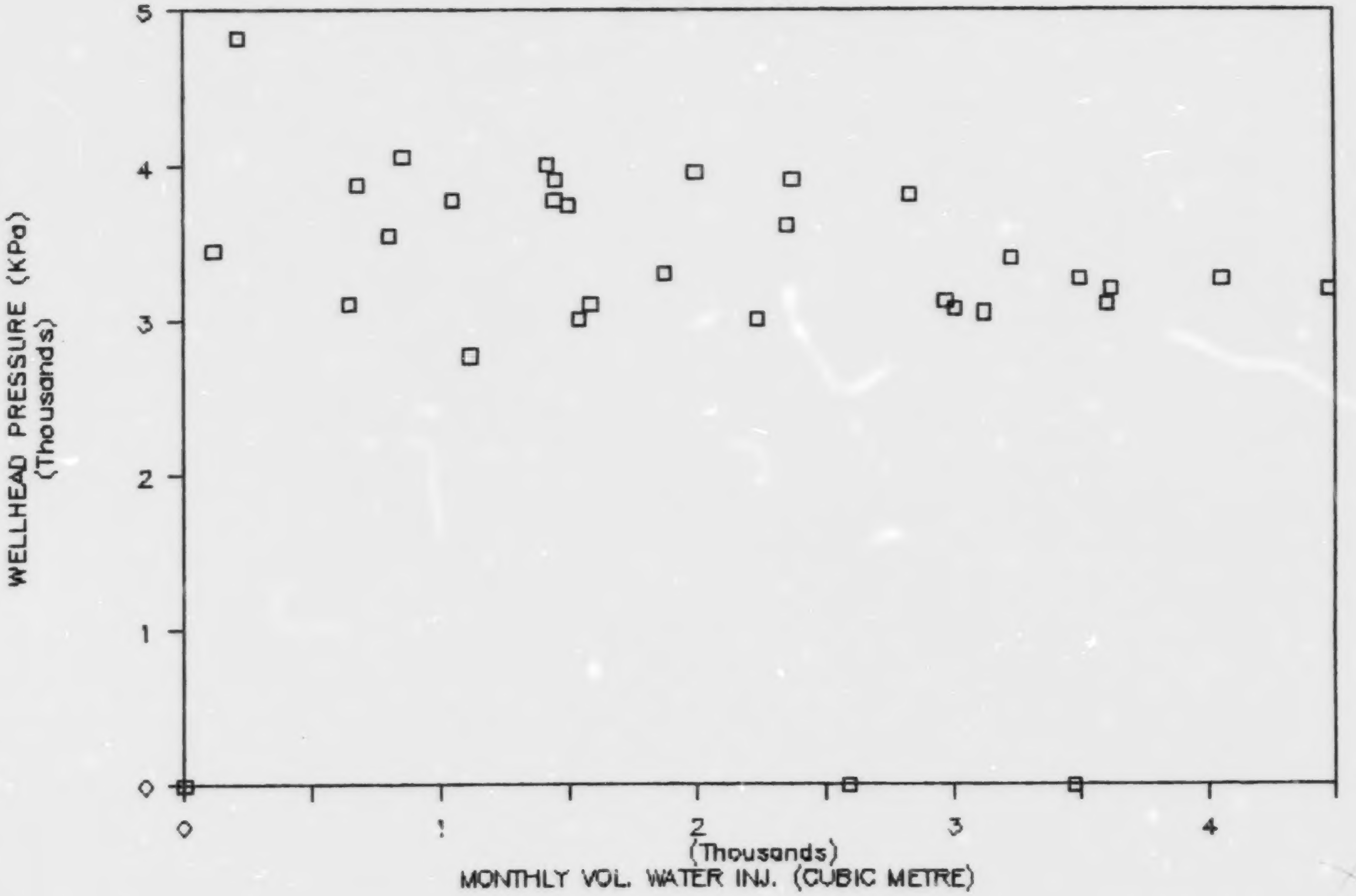
DOME ET AL LINDBERGH 11-24-55-6 W4M

(1986-1987)



AMOCO SWD LINDBERGH 9-28-55-6 W4M

(1985-1987)



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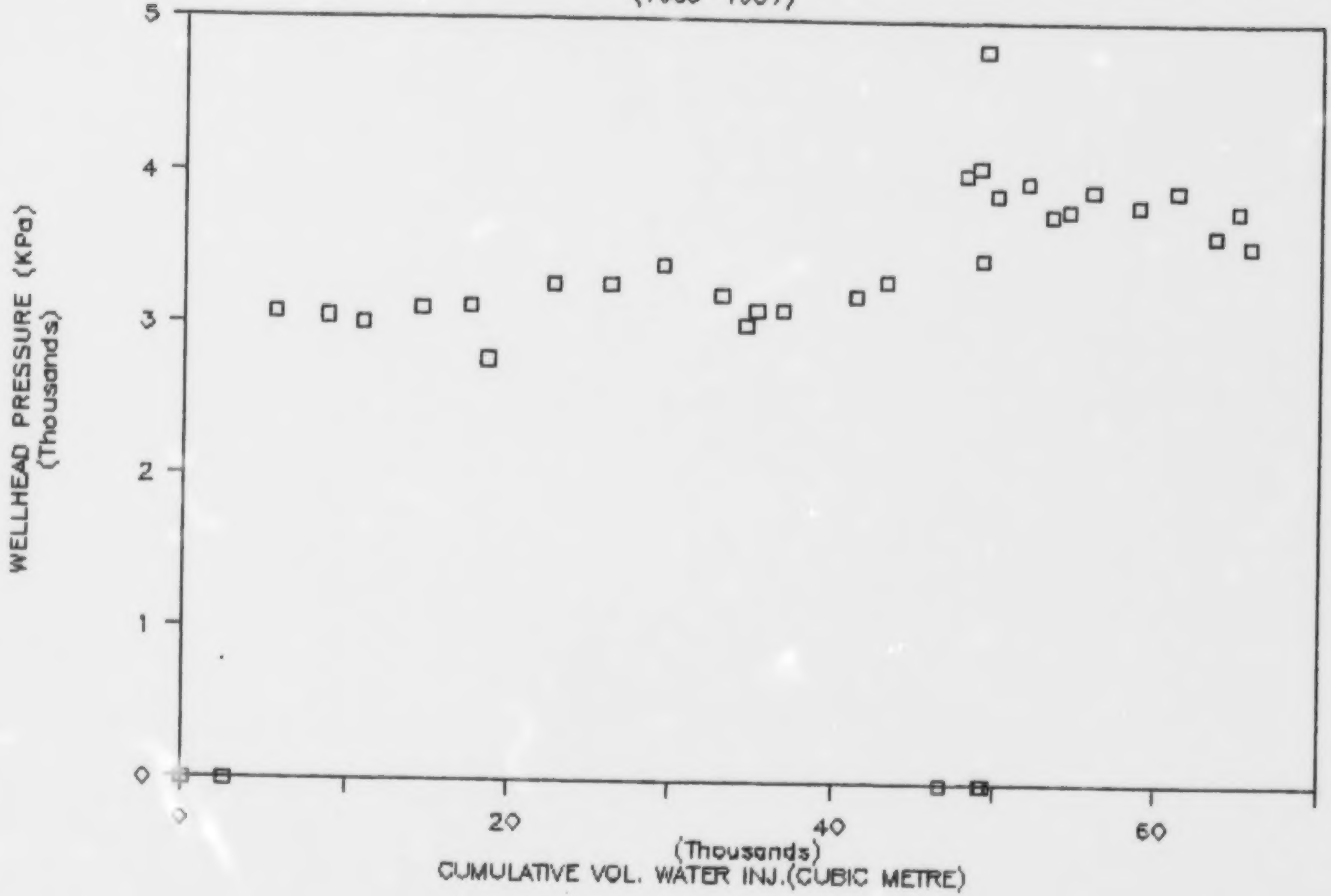
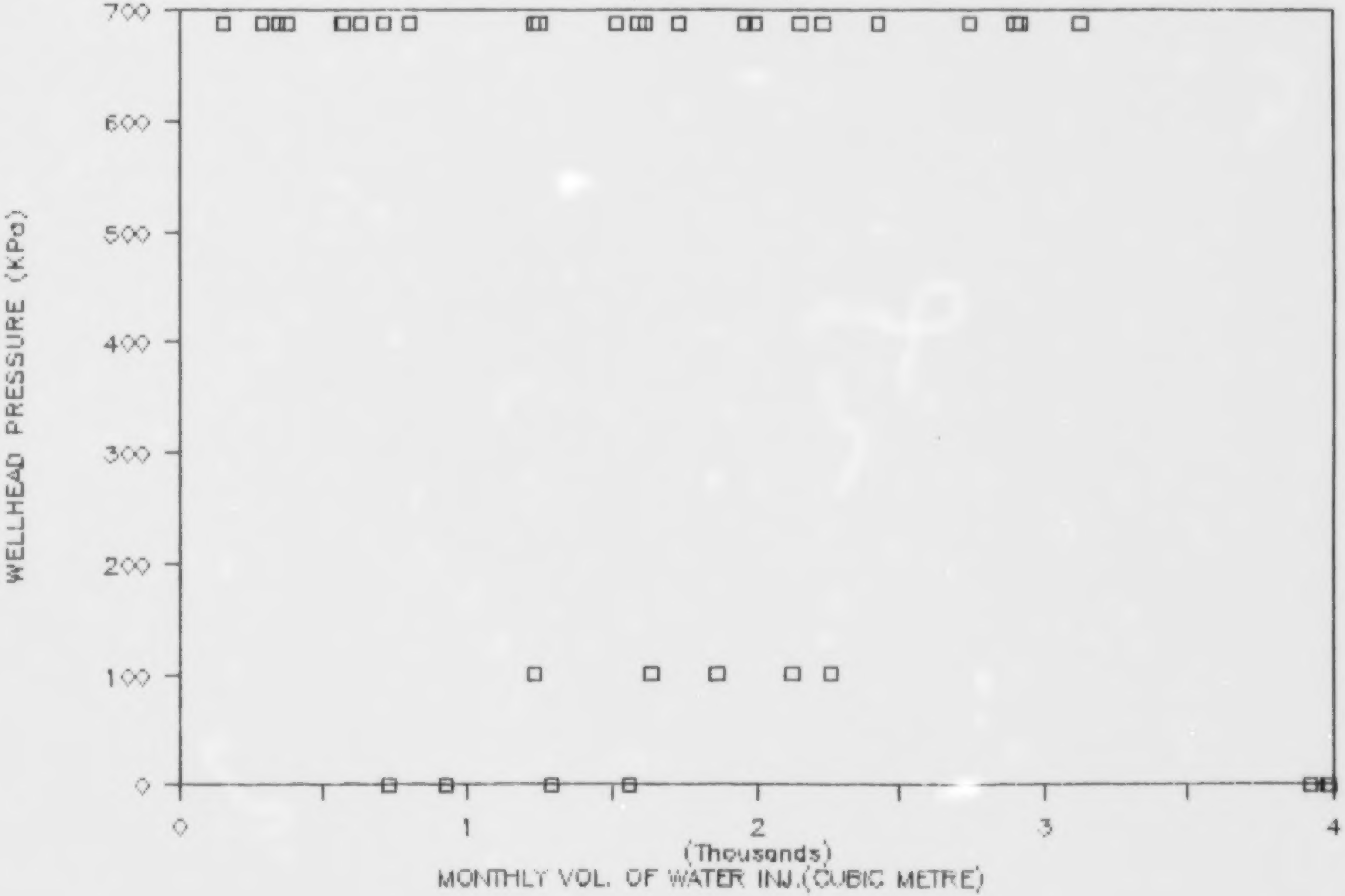
(1985–1987)



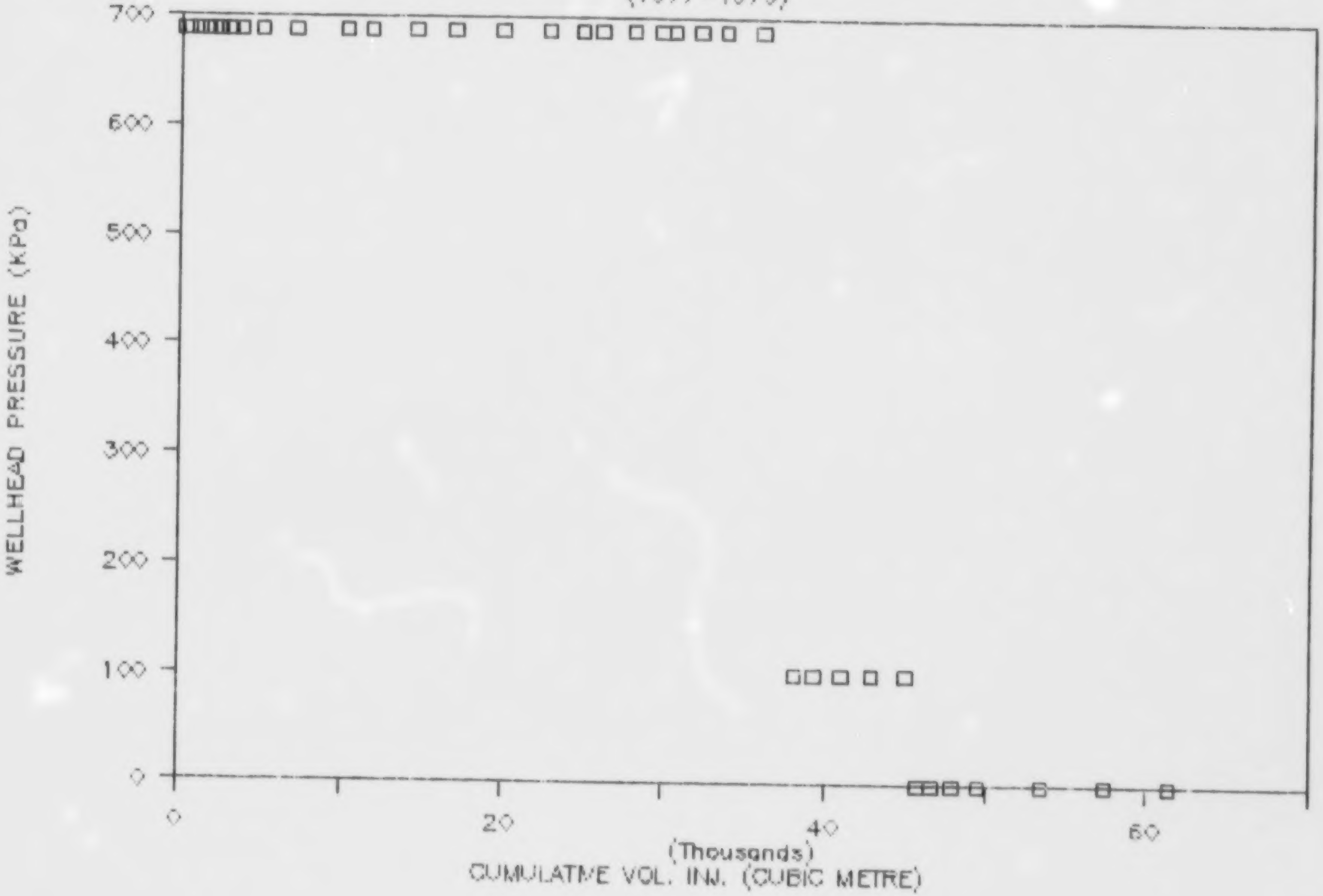
MINERALS HAIRY 7-22-55-14 W4M

(1977-1979)



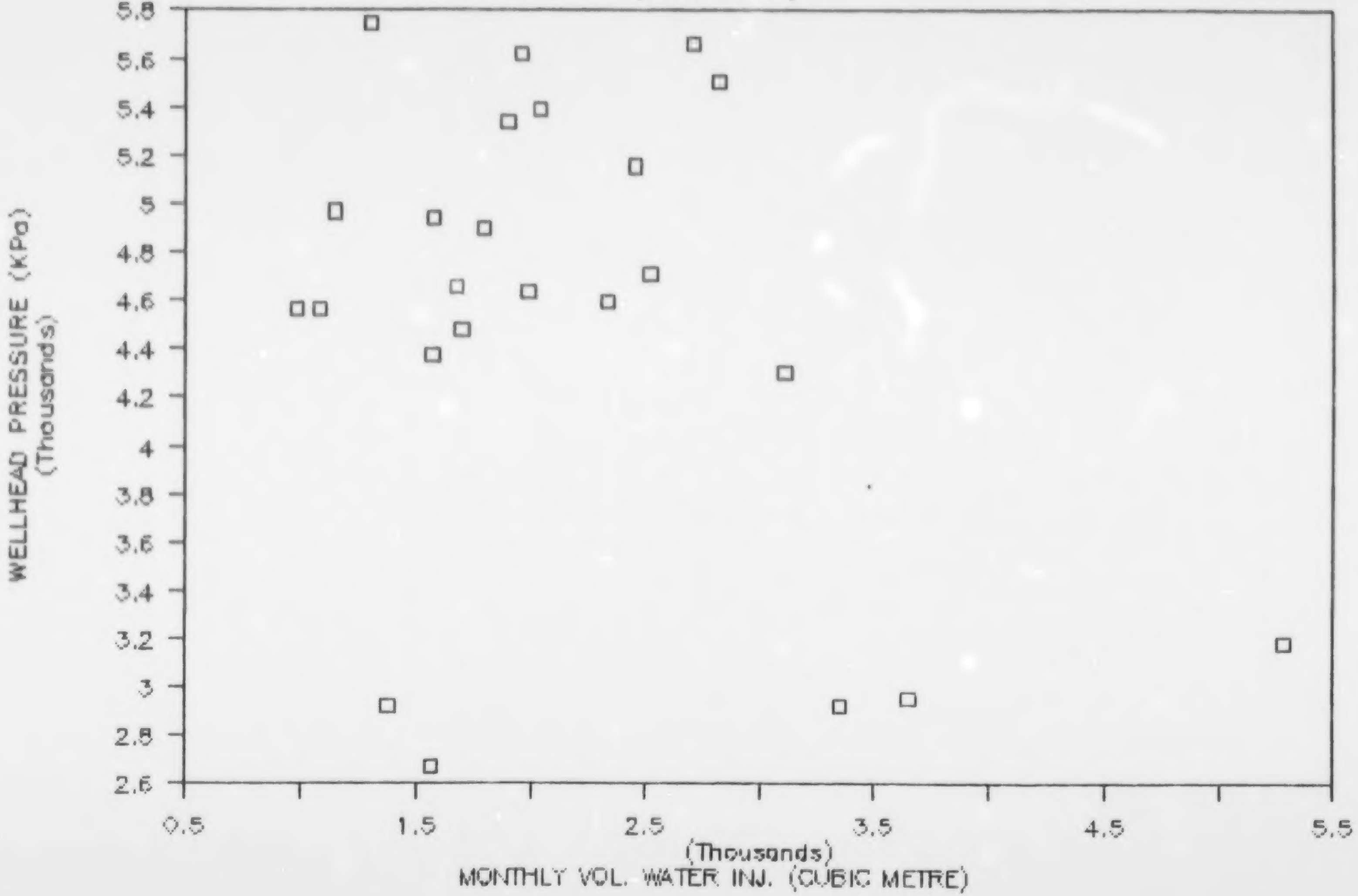
MINERALS HAIRY 7-22-55-14 W4M

(1977-1979)



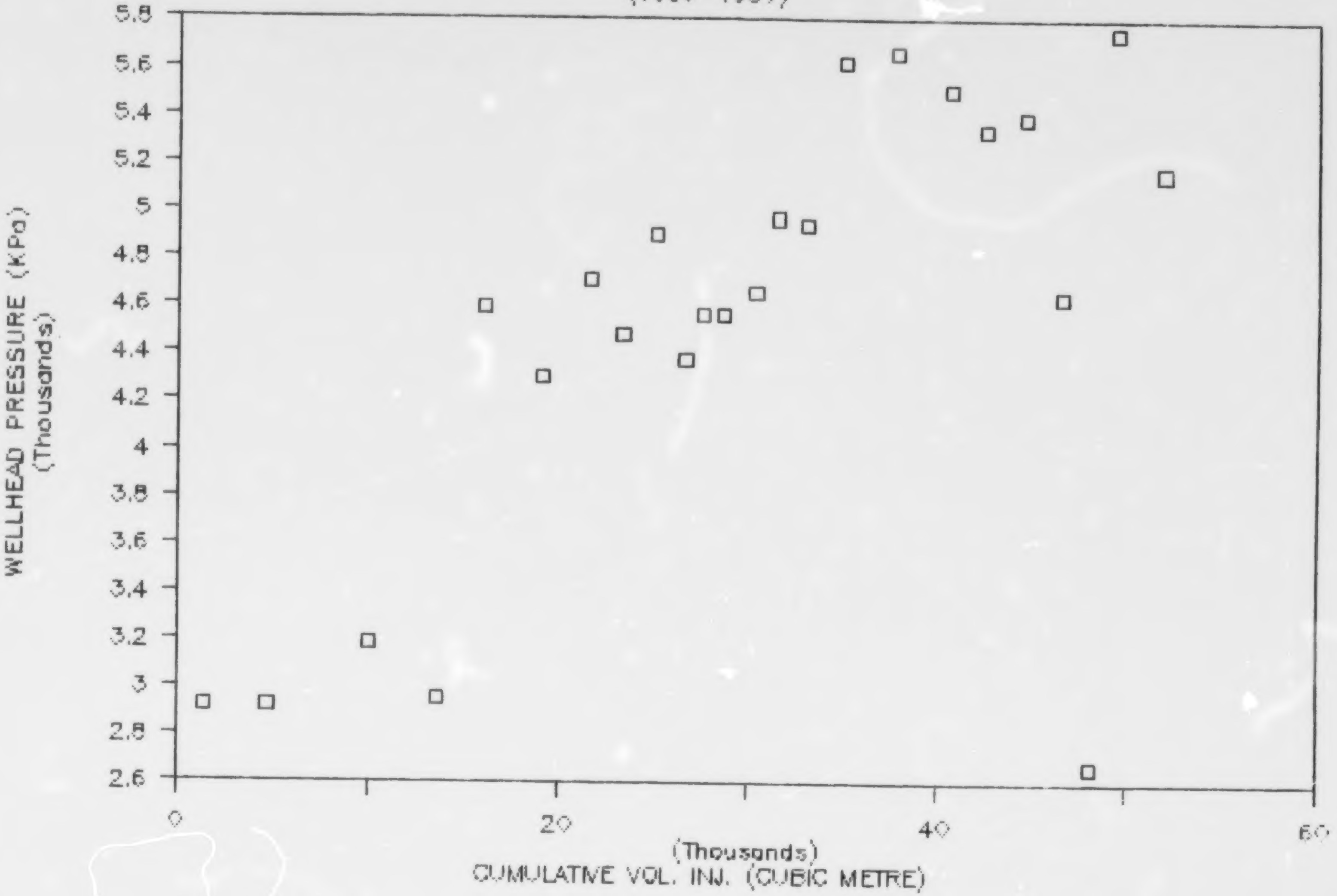
PCP LINDBERGH 6-3-56-6 W4M

(1986-1987)



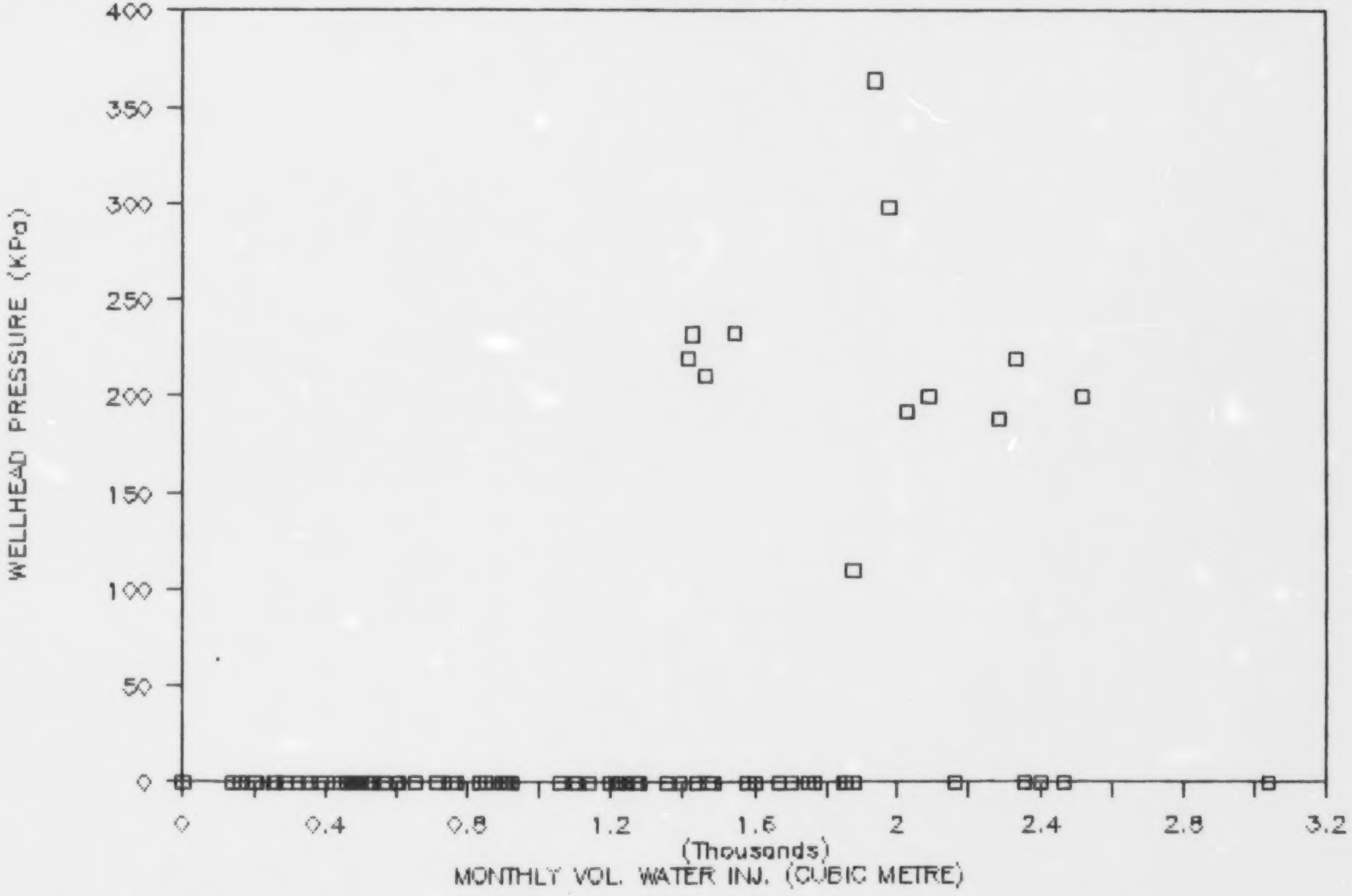
PCP LINDBERGH 6-3-56-6 W4M

(1986-1987)



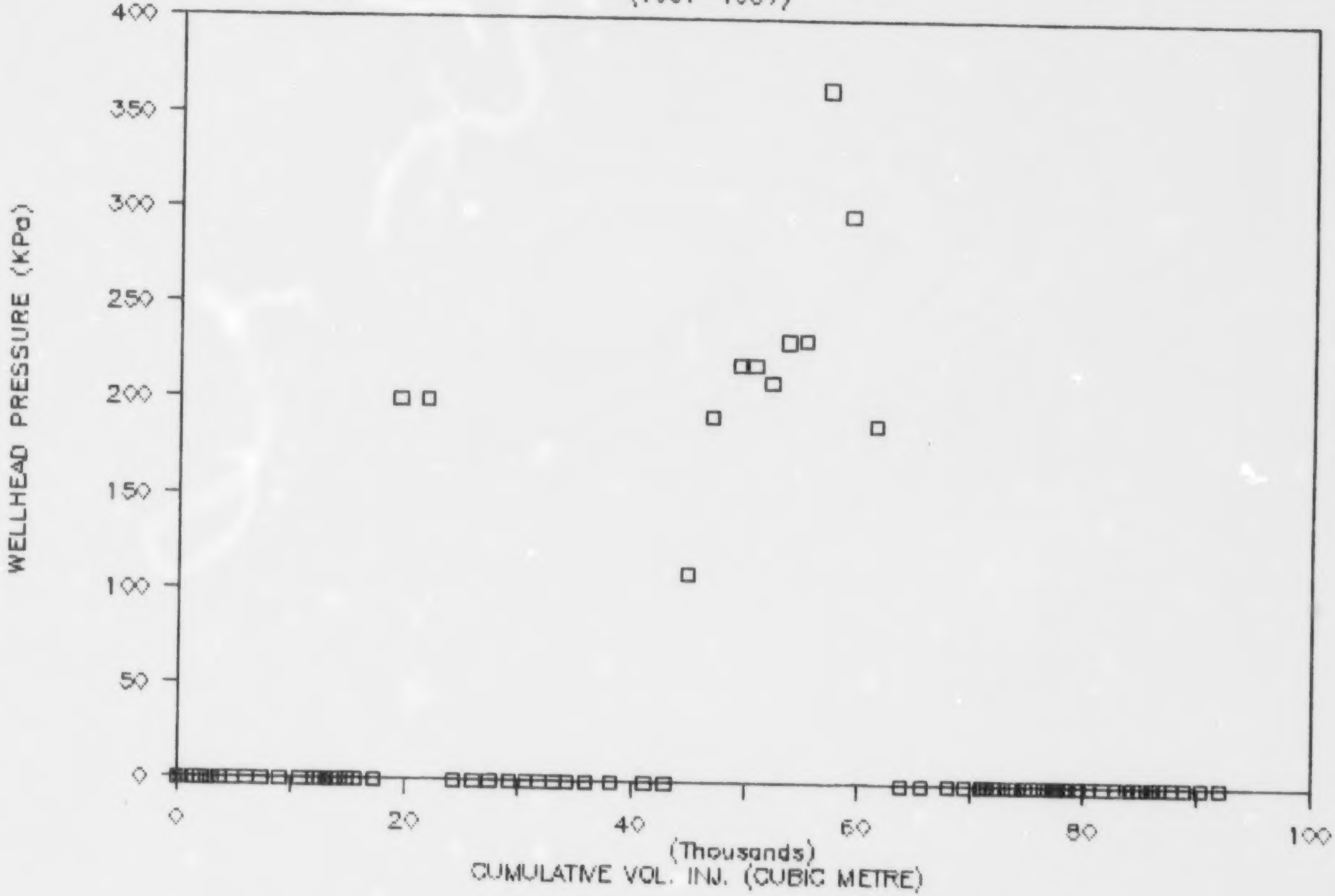
MERLAND BRASCAN UKALTA 12-31-56-17 W4M

(1981 - 1987)



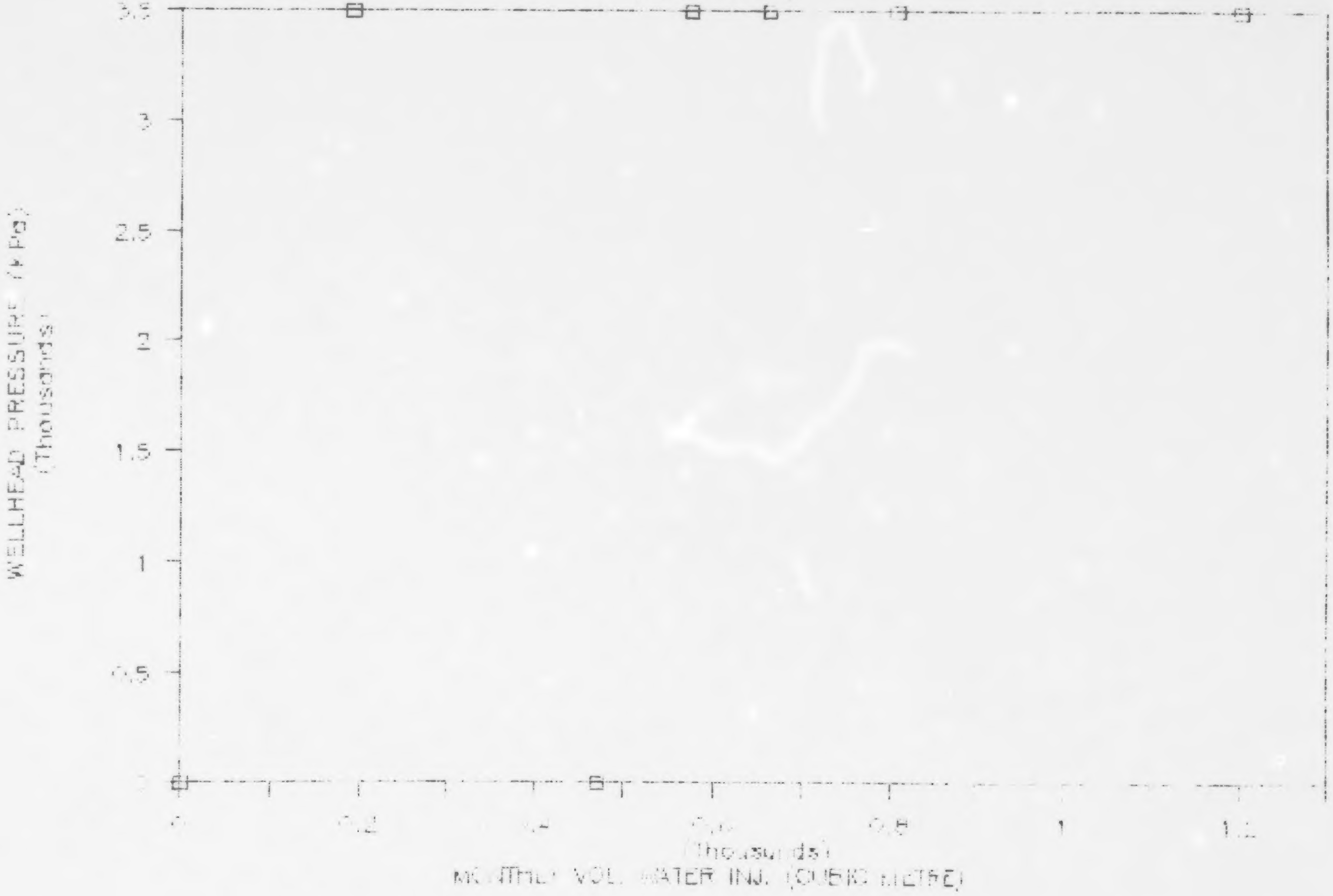
MERLAND BRASCAN UKALTA 12-31-56-17 W4M

(1981 - 1987)



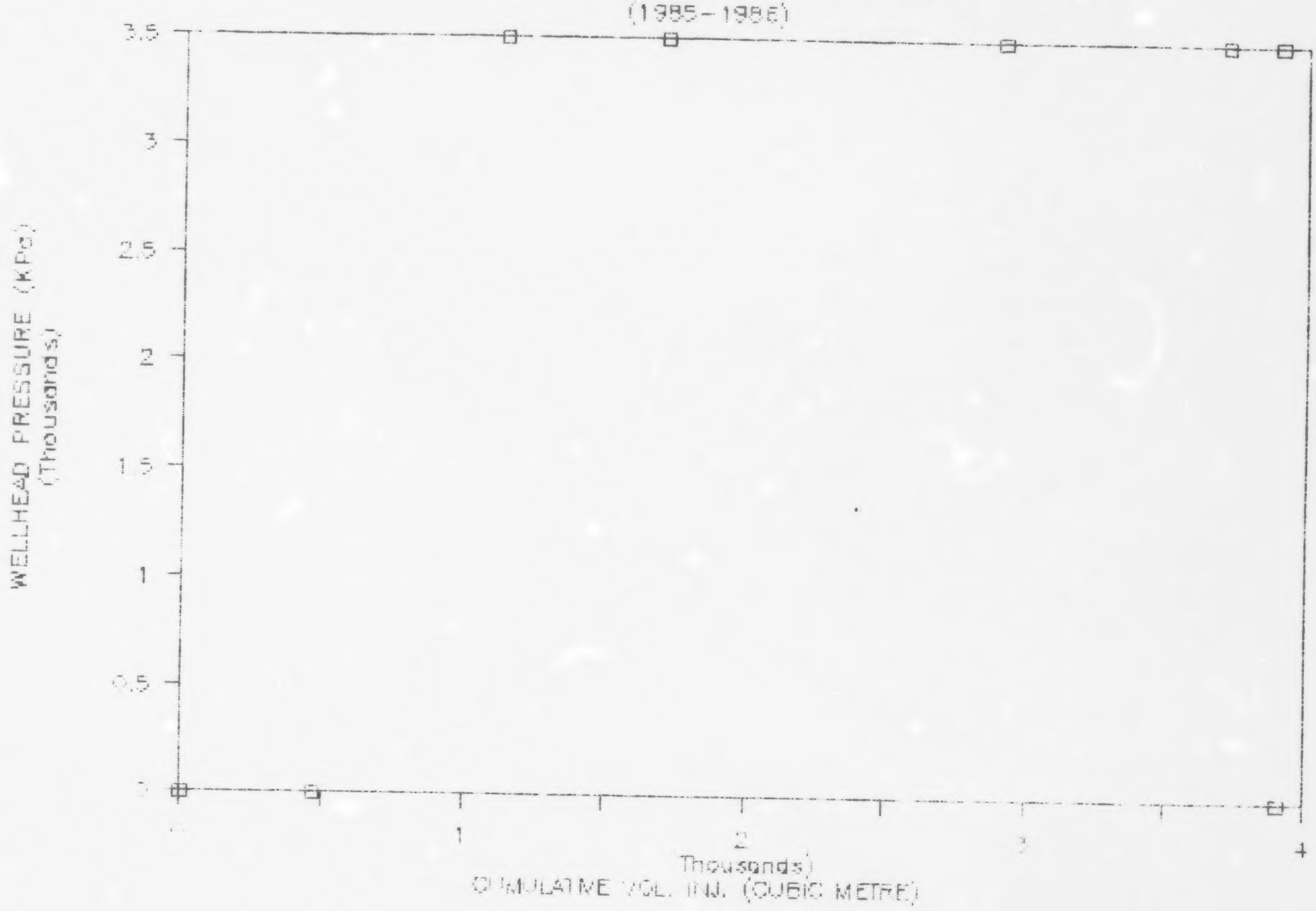
CANOXY LINDBERGH 5-18-58-4 W4M

(1985-1986)



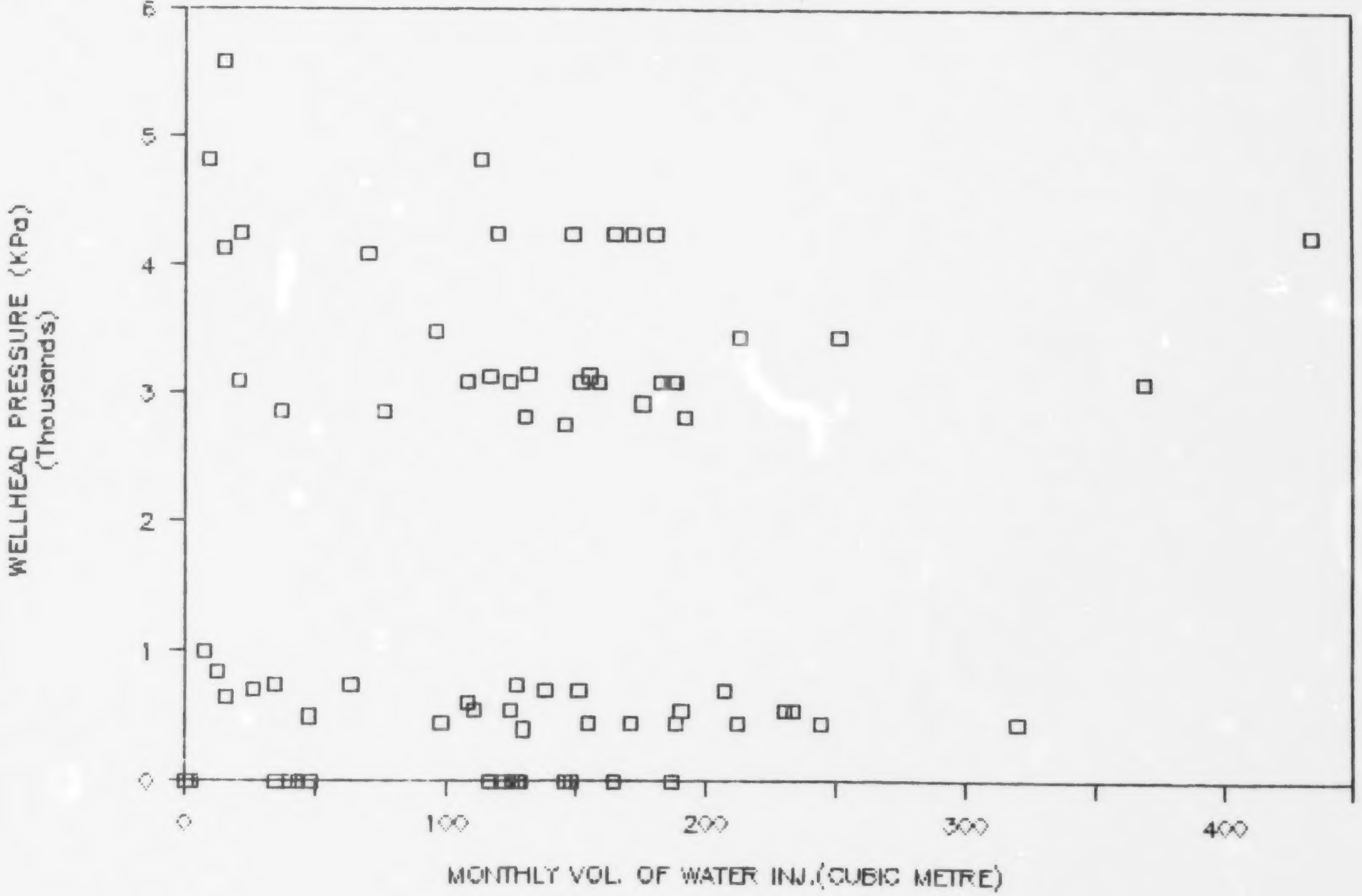
CANOXY LINDBERGH 5-18-58-4 W4M

(1985–1986)



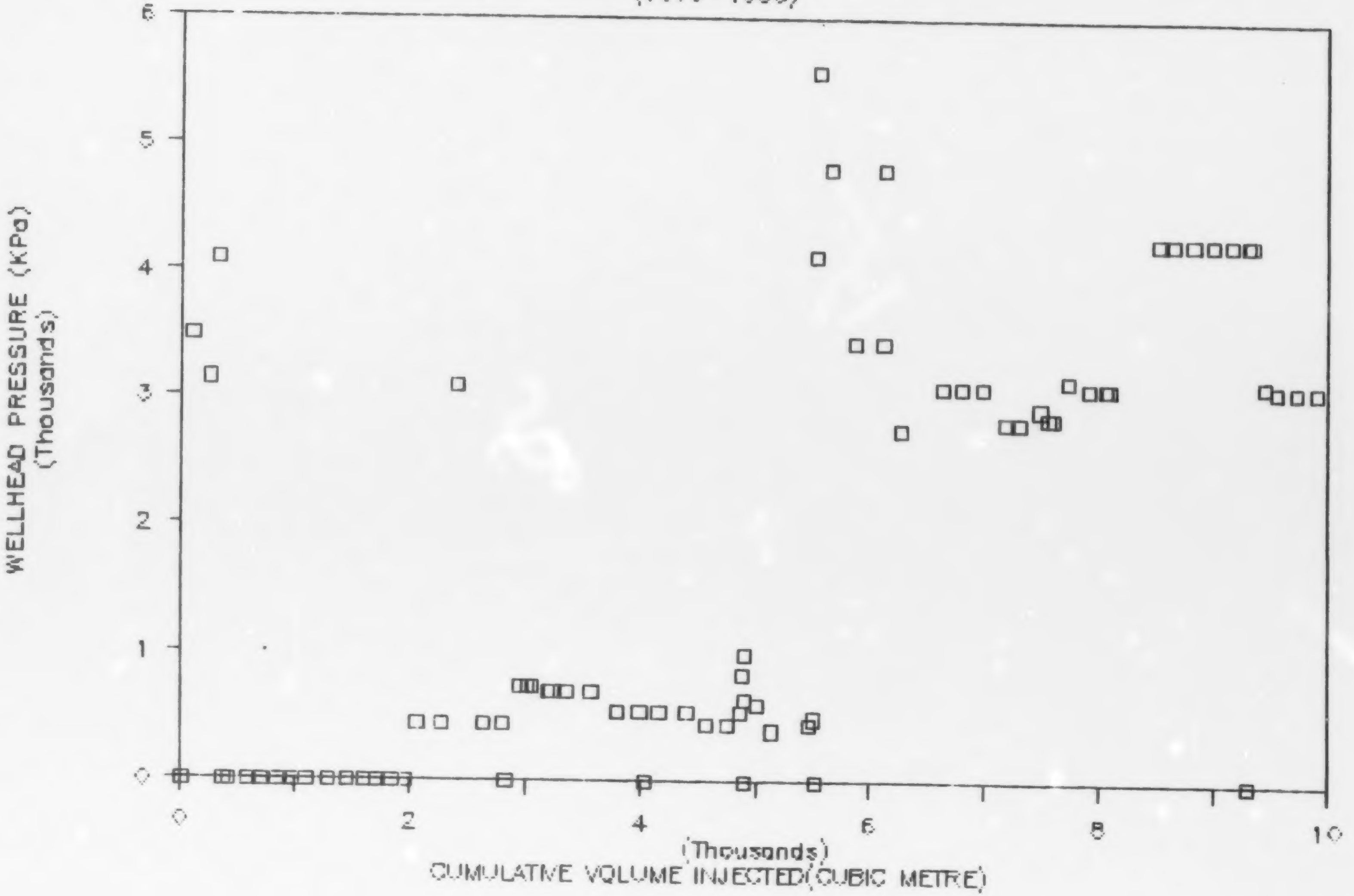
BP BGUI BELLIS 12-4-60-15 W4M

(1979 - 1985)



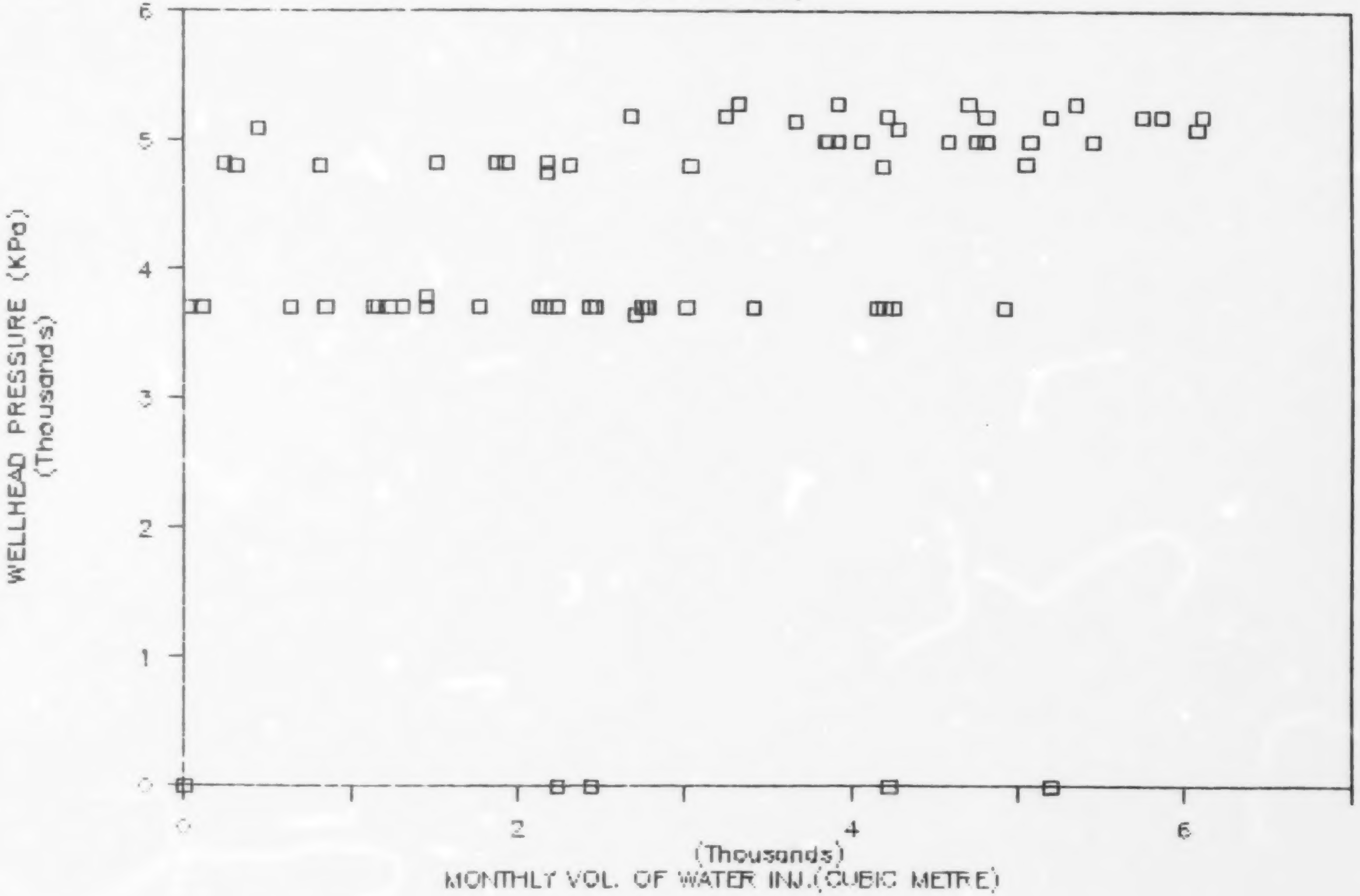
BP BGUI BELLIS 12-4-60-15 W4M

(1979–1985)



CCL SWD BEAVER CROSSING 8-36-61-2 W4M

(1979-1985)



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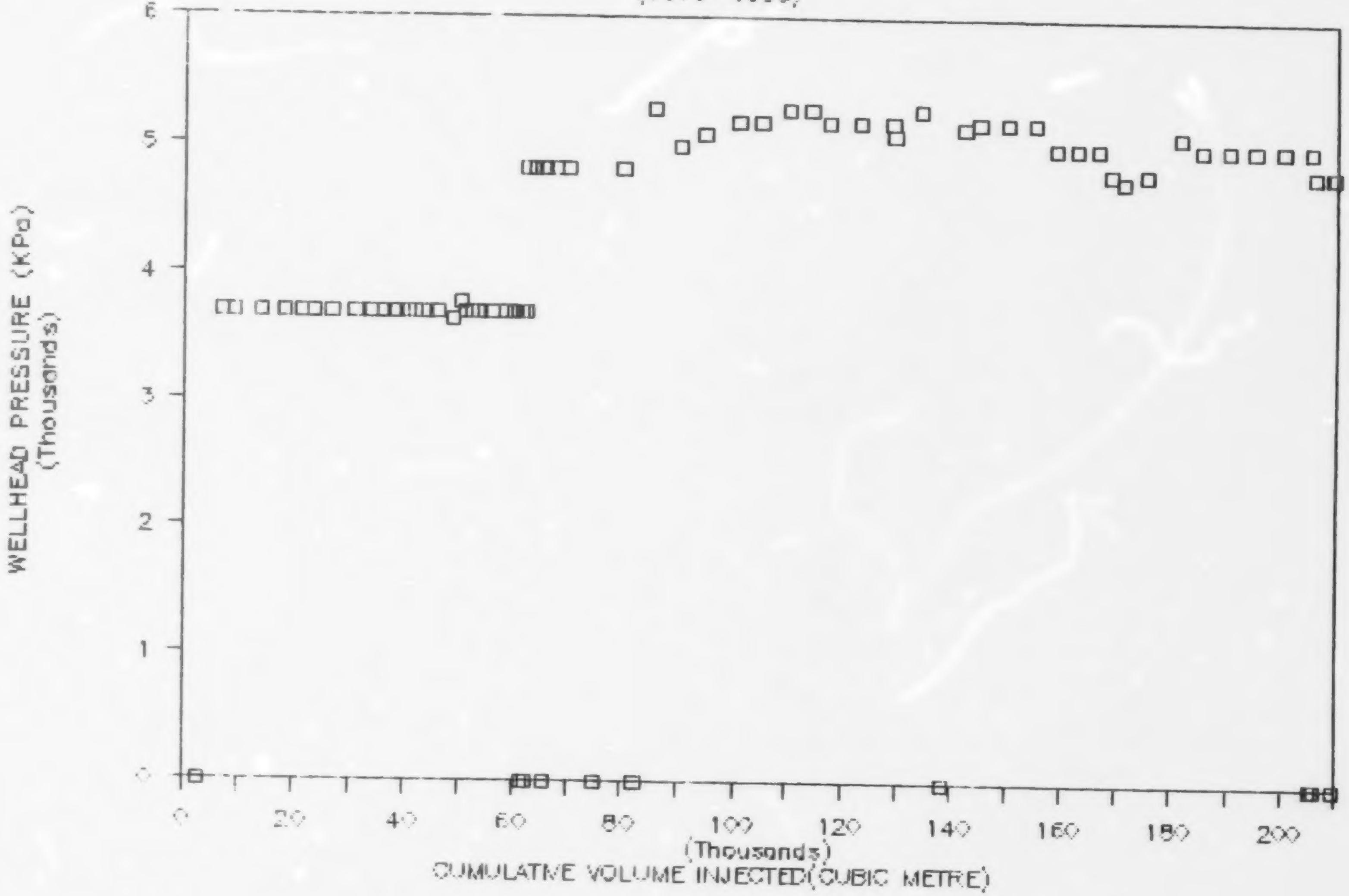
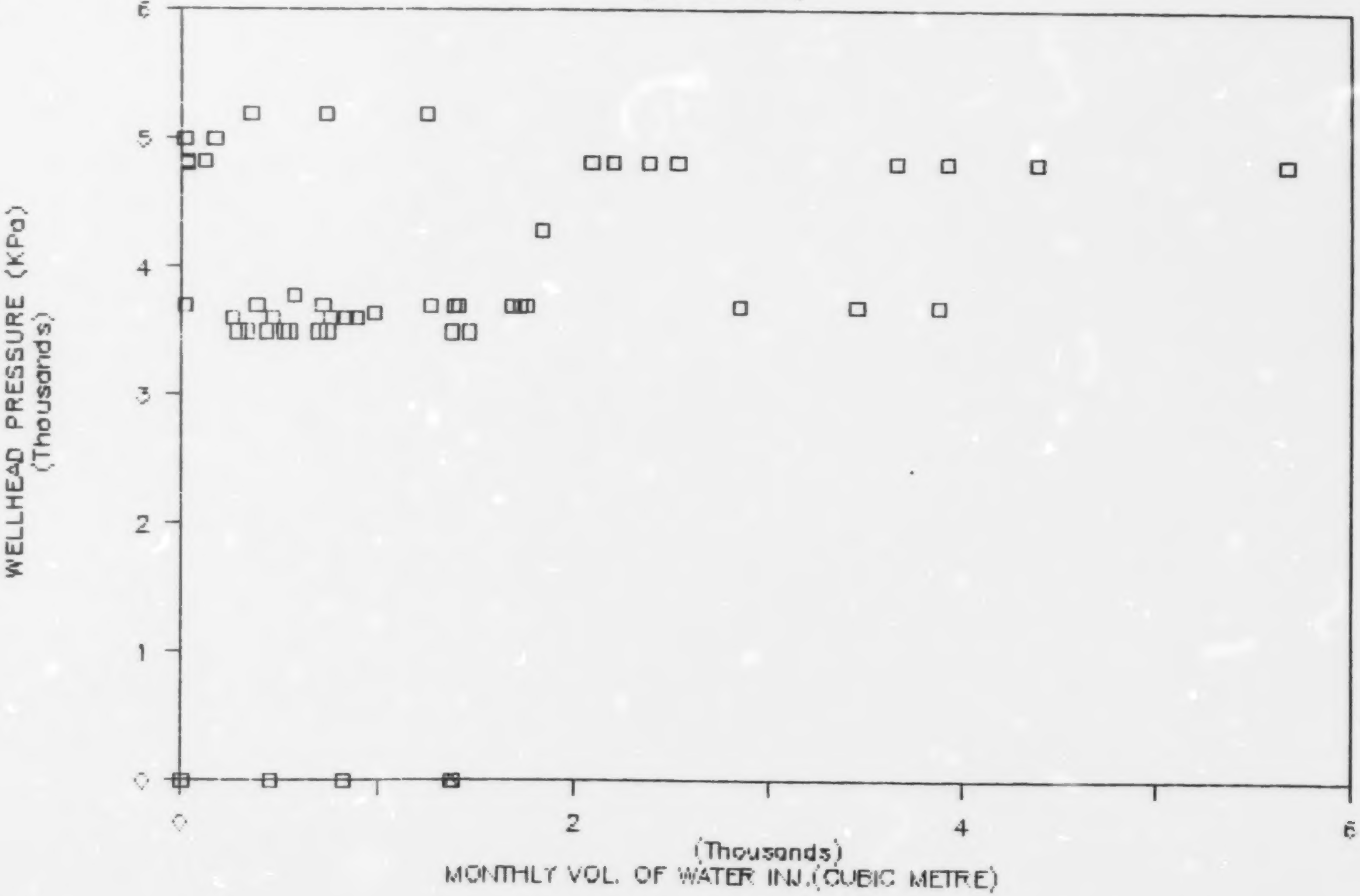
(1979 – 1985)



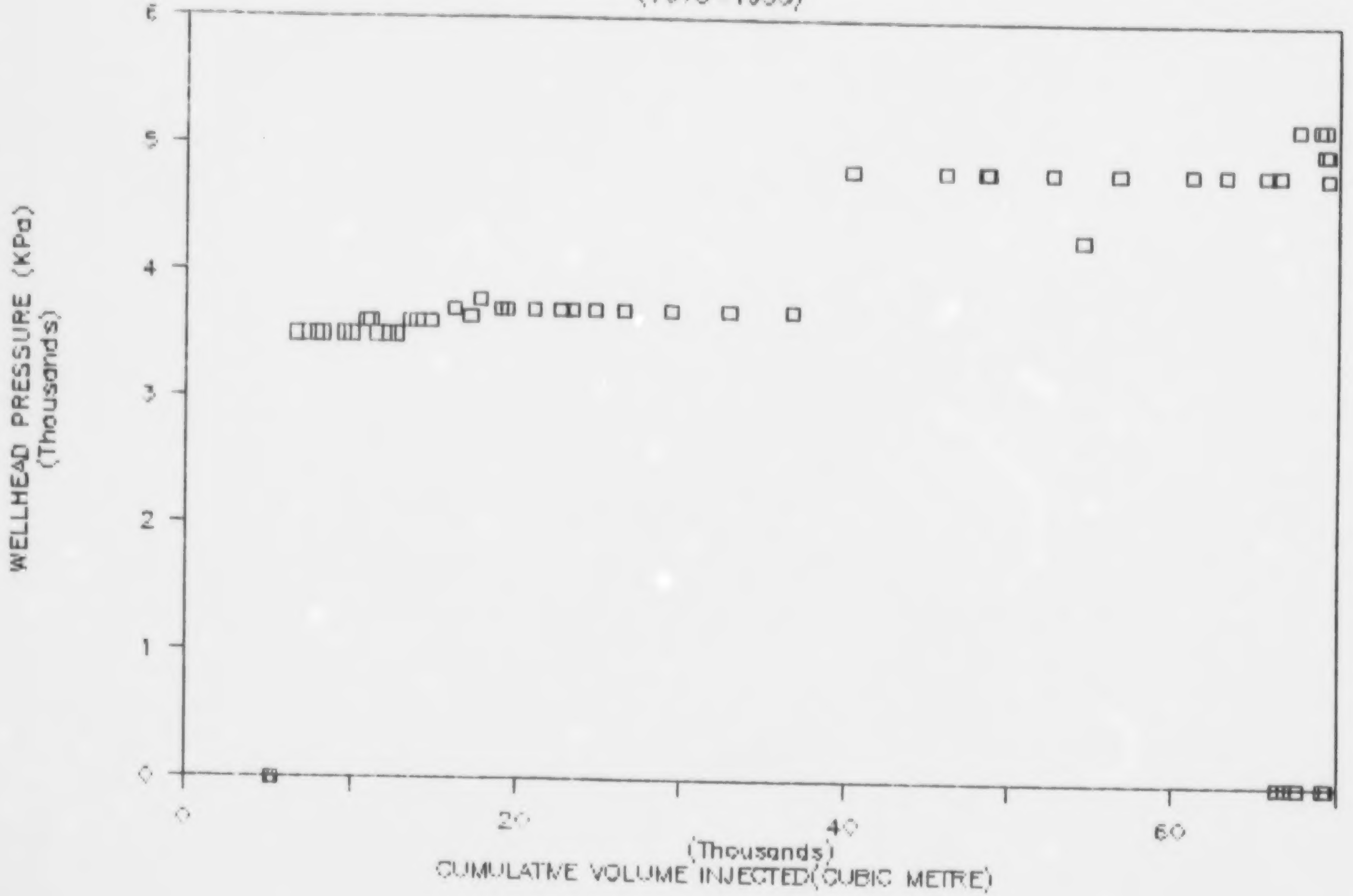
CCL SWD BEAVER CROSSING 16-36-61-2 W4M

(1978-1985)



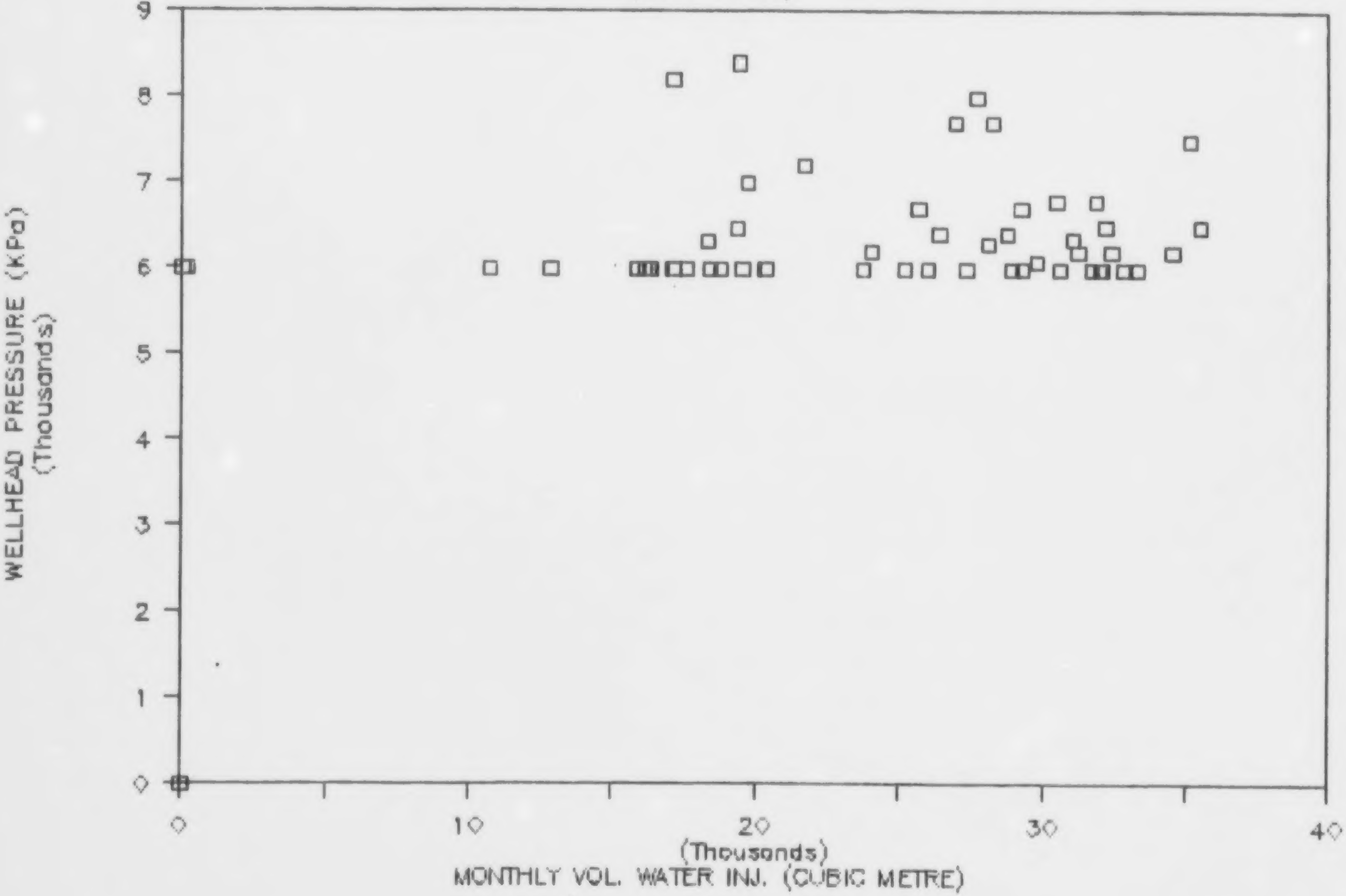
CCL SWD BEAVER CROSSING 16-36-61-2 W4M

(1978-1985)



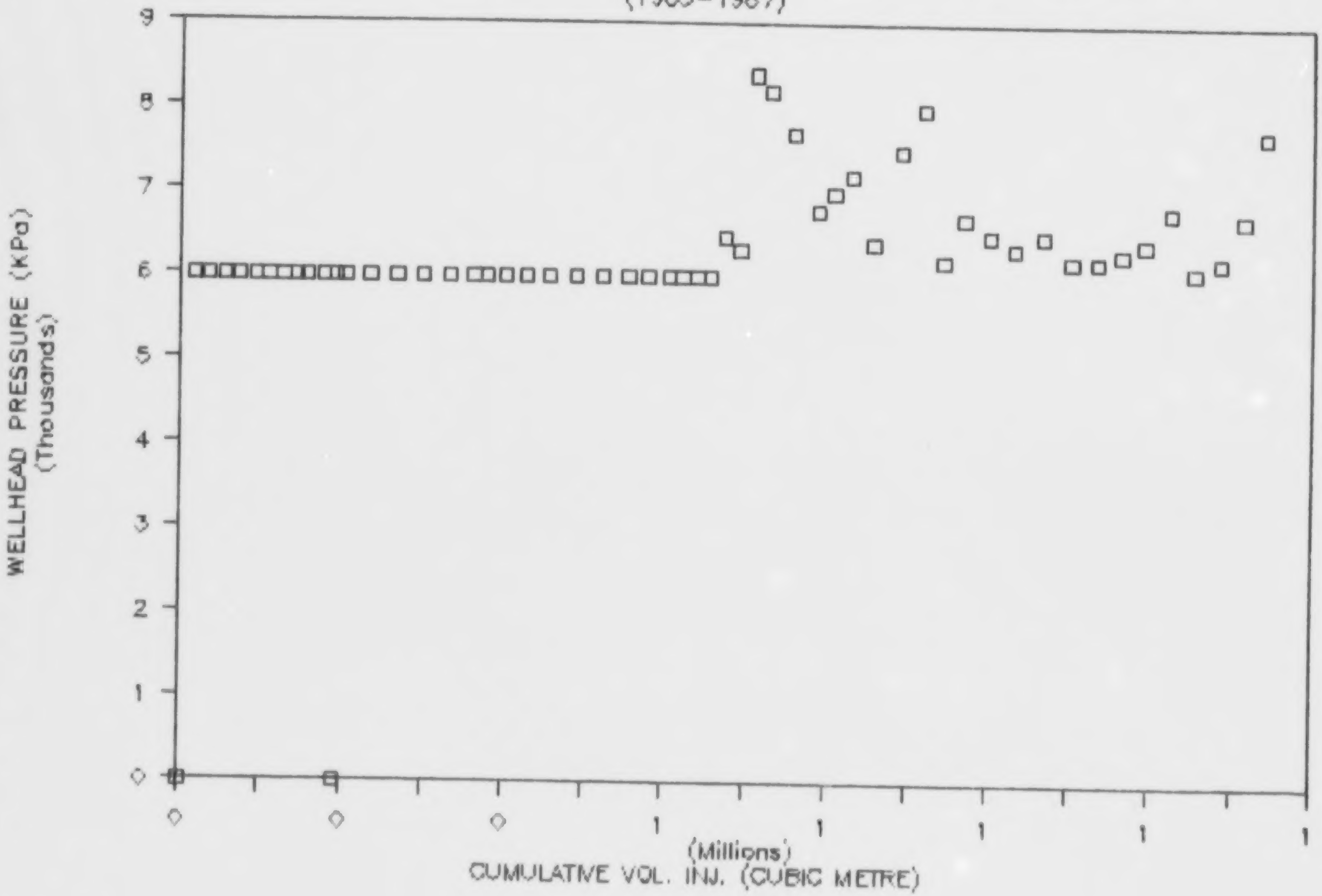
SUNCOR WECO FORT KENT 2-28-61-4 W4M

(1983-1987)



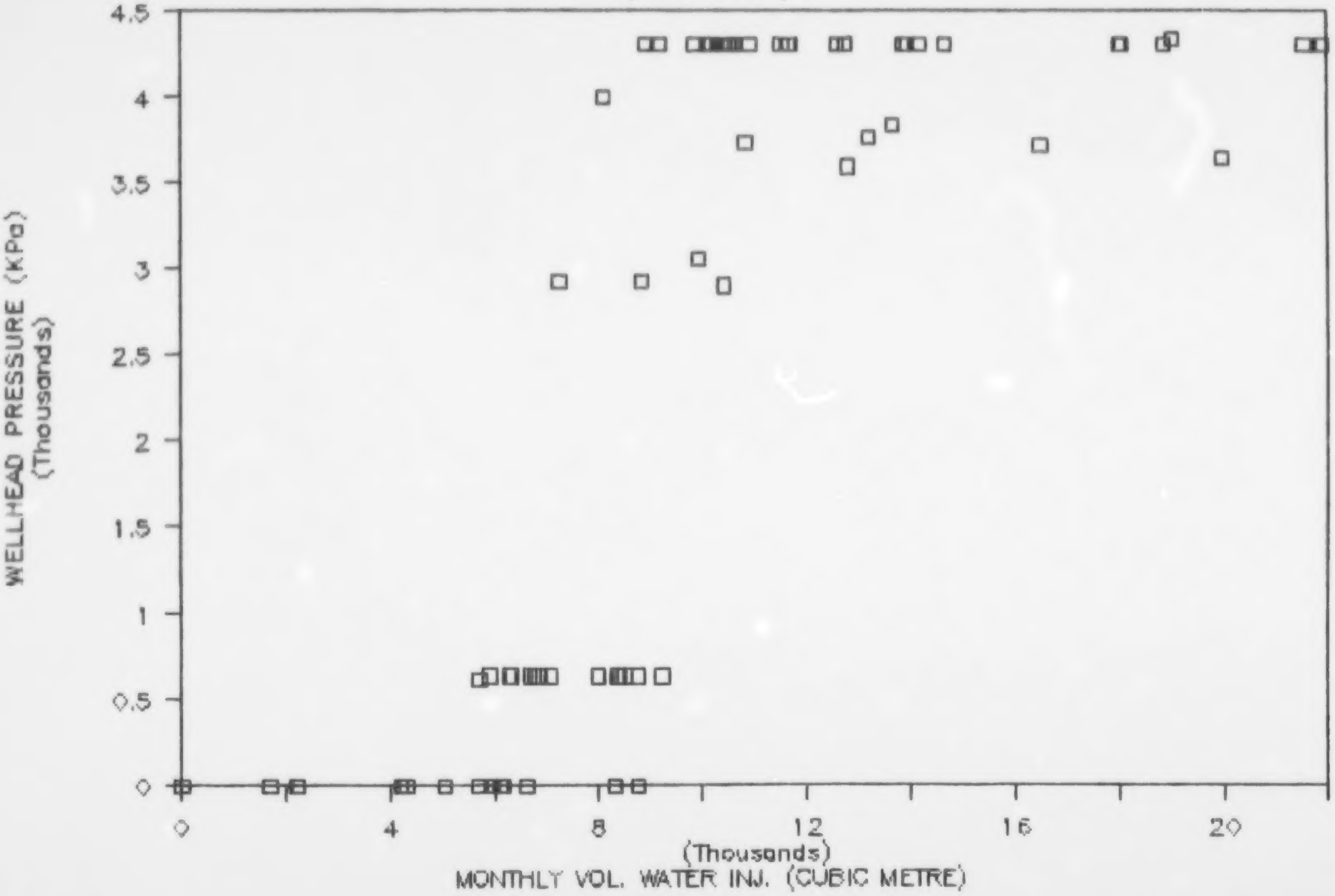
SUNCOR WECO FORT KENT 2-28-61-4 W4M

(1983–1987)



DOME ET AL 10D SWD 10D-18-55-5 W4M

(1980–1987)



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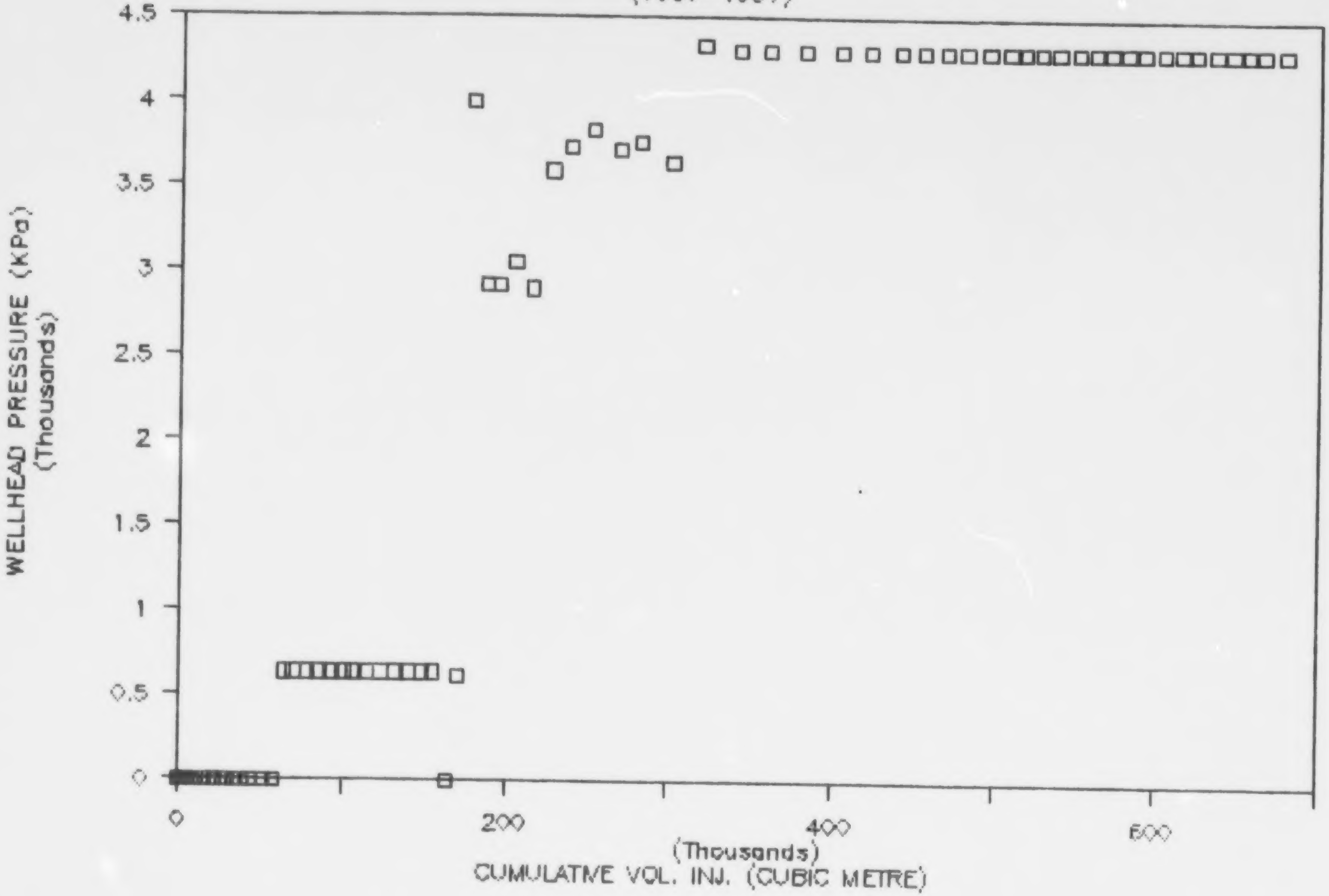
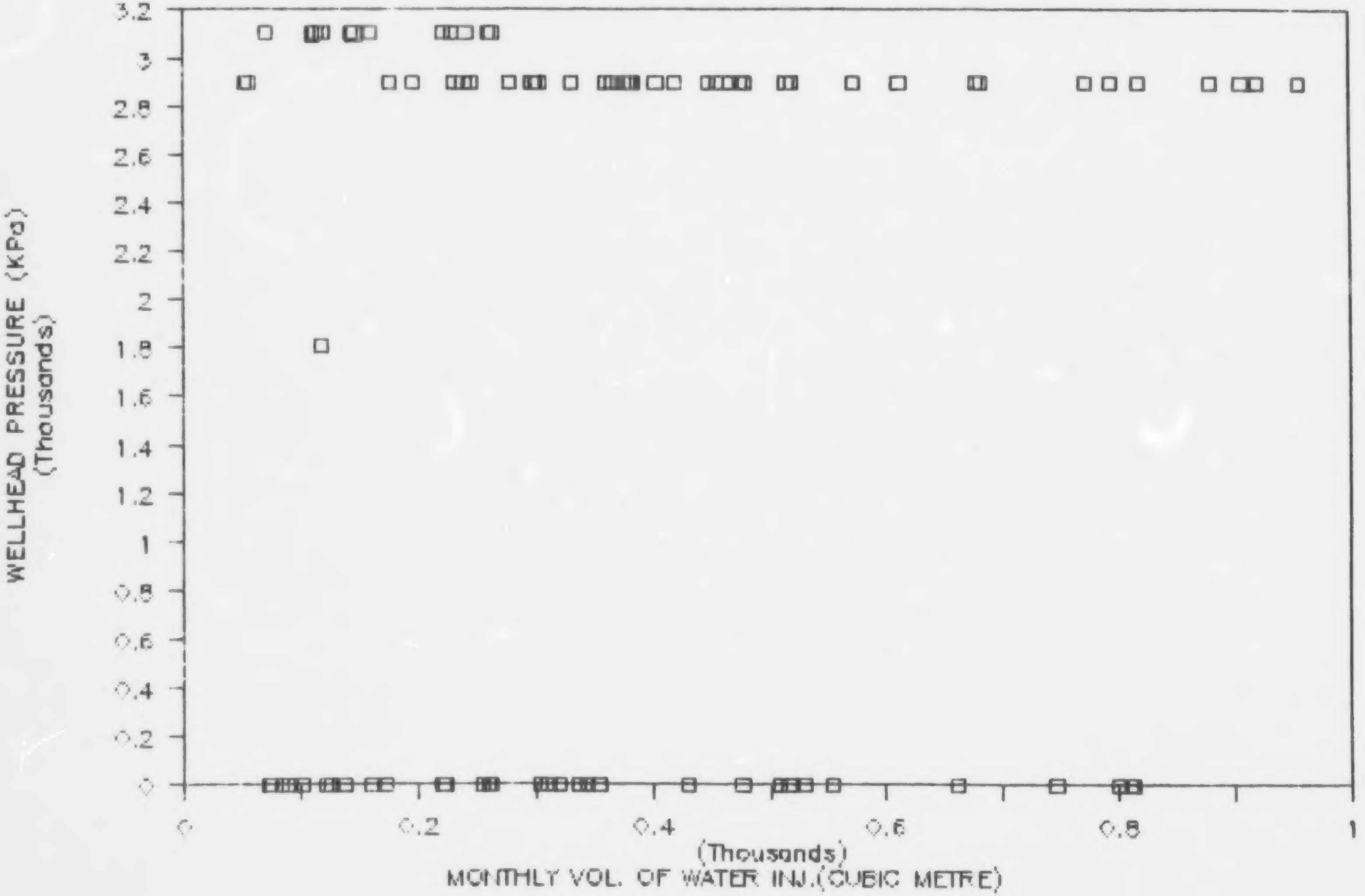
(1980-1987)



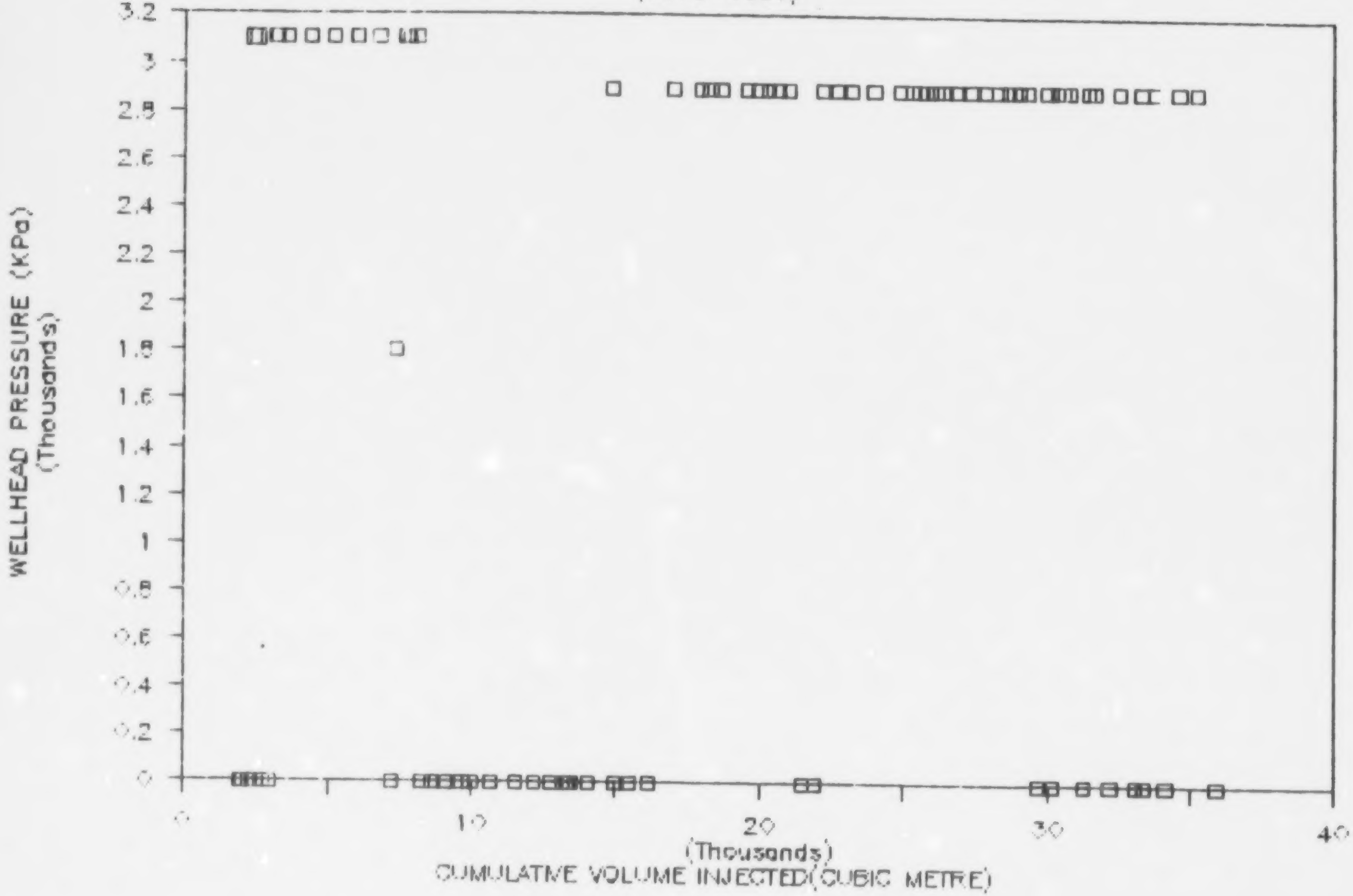
FINA CACHE 10-18-58-11 W4M

(1978–1987)



FINA CACHE 10-18-58-11 W4M

(1978–1987)



SUNCOR CWWE FTKENT 5A-28-61-4 W4M

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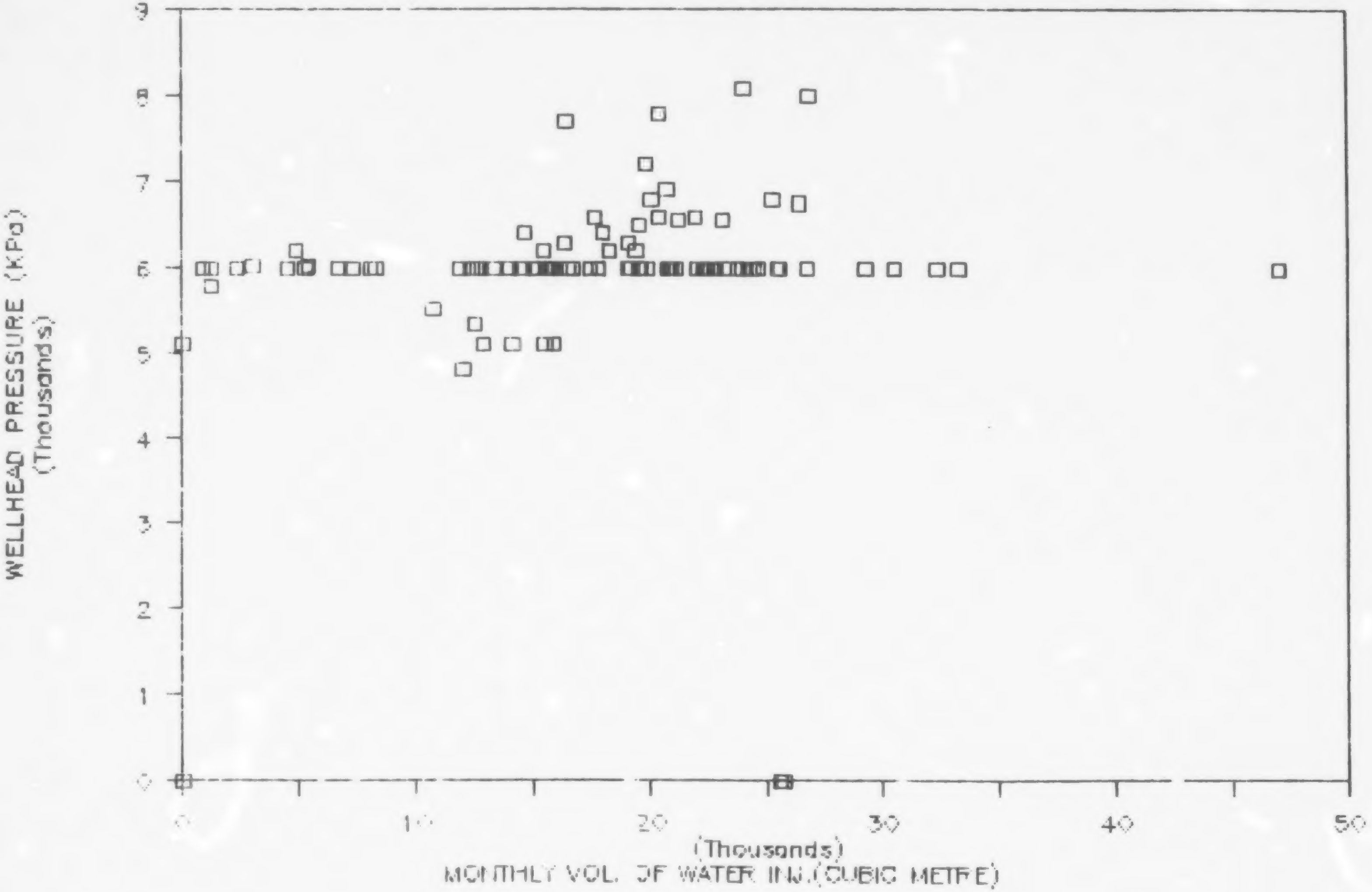

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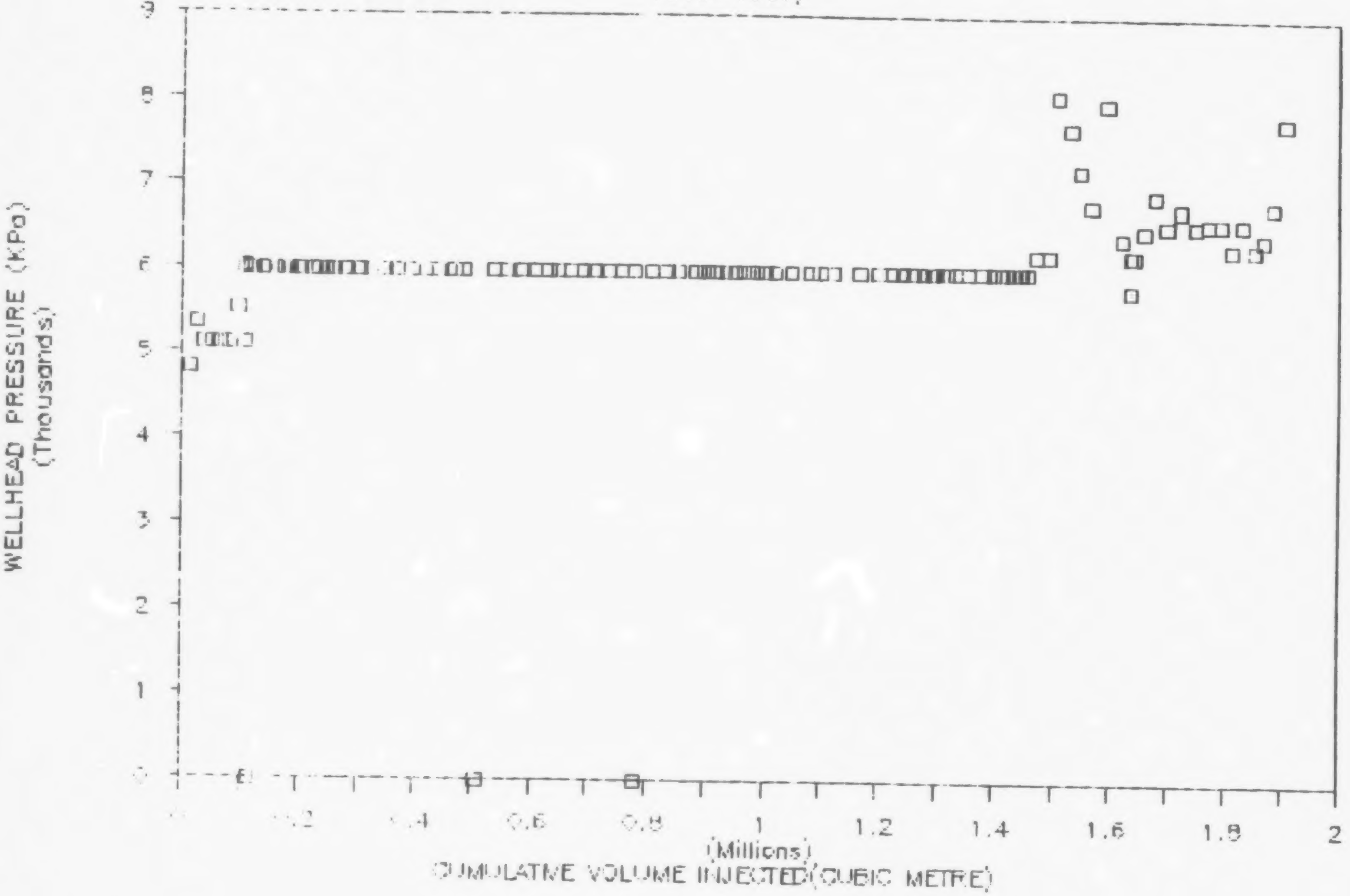
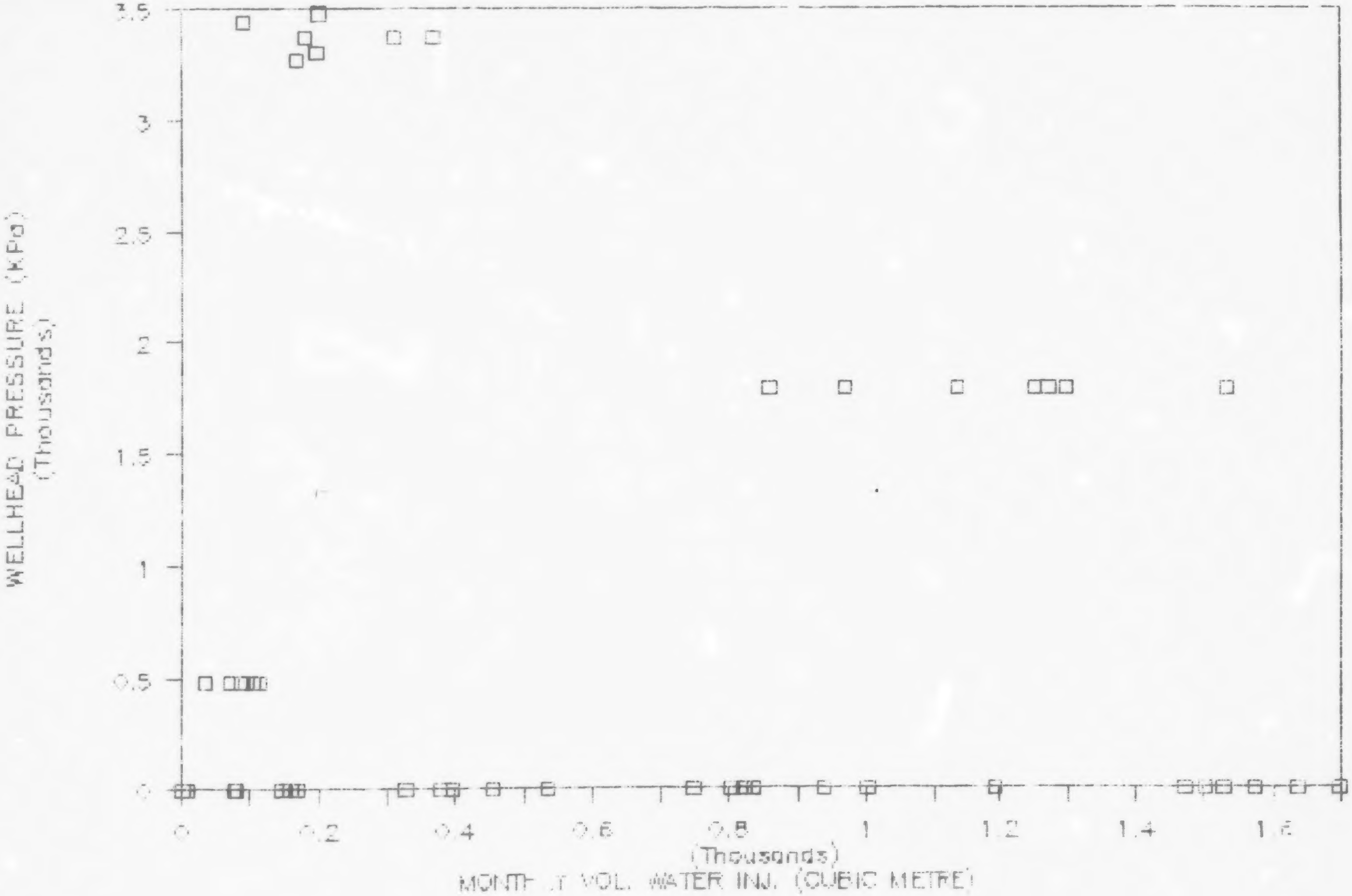
(1979 - 1987)



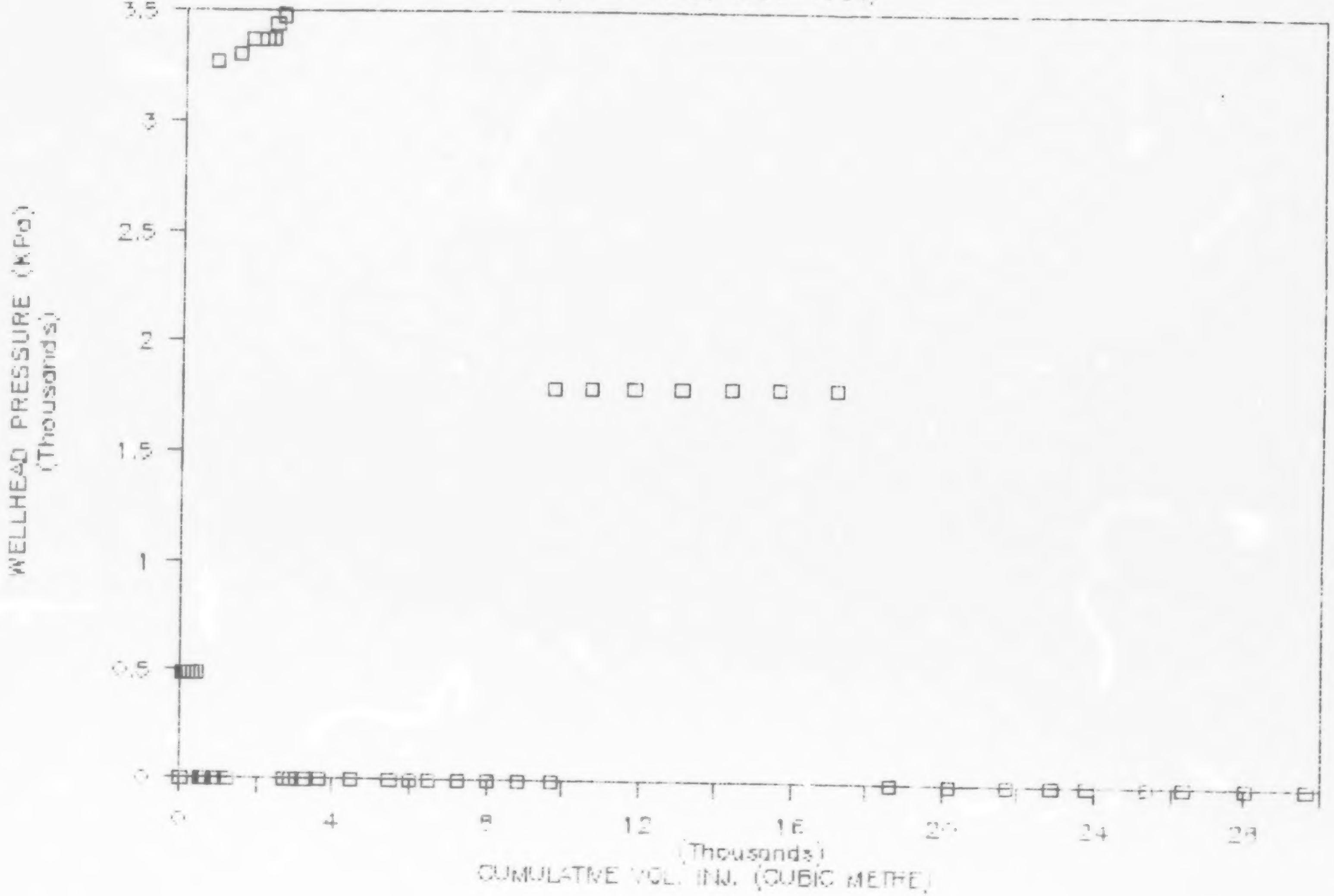
PROVIDENT HANMORE 6-1-61-17 W4M

(1977–1979, 1983–1984)



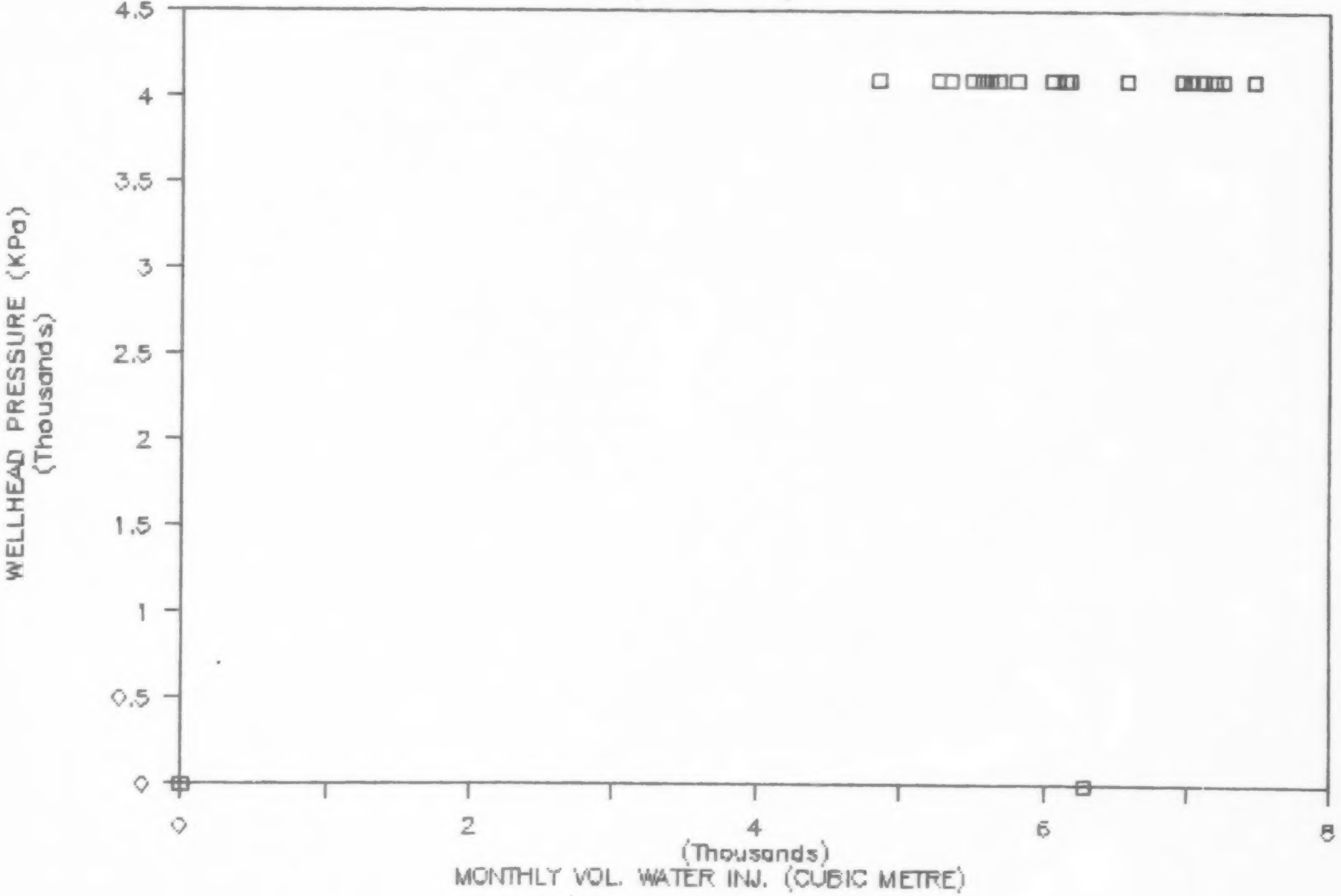
PROVIDENT HANMORE 6-1-61-17 W4M

(1977–1979, 1983–1984)



UTEXCAN ET AL ARDMORE EX 13-20-62-3 W4M

(1986–1987)



UTEXCAN ET AL ARDMORE EX 13-20-62-3 W4M

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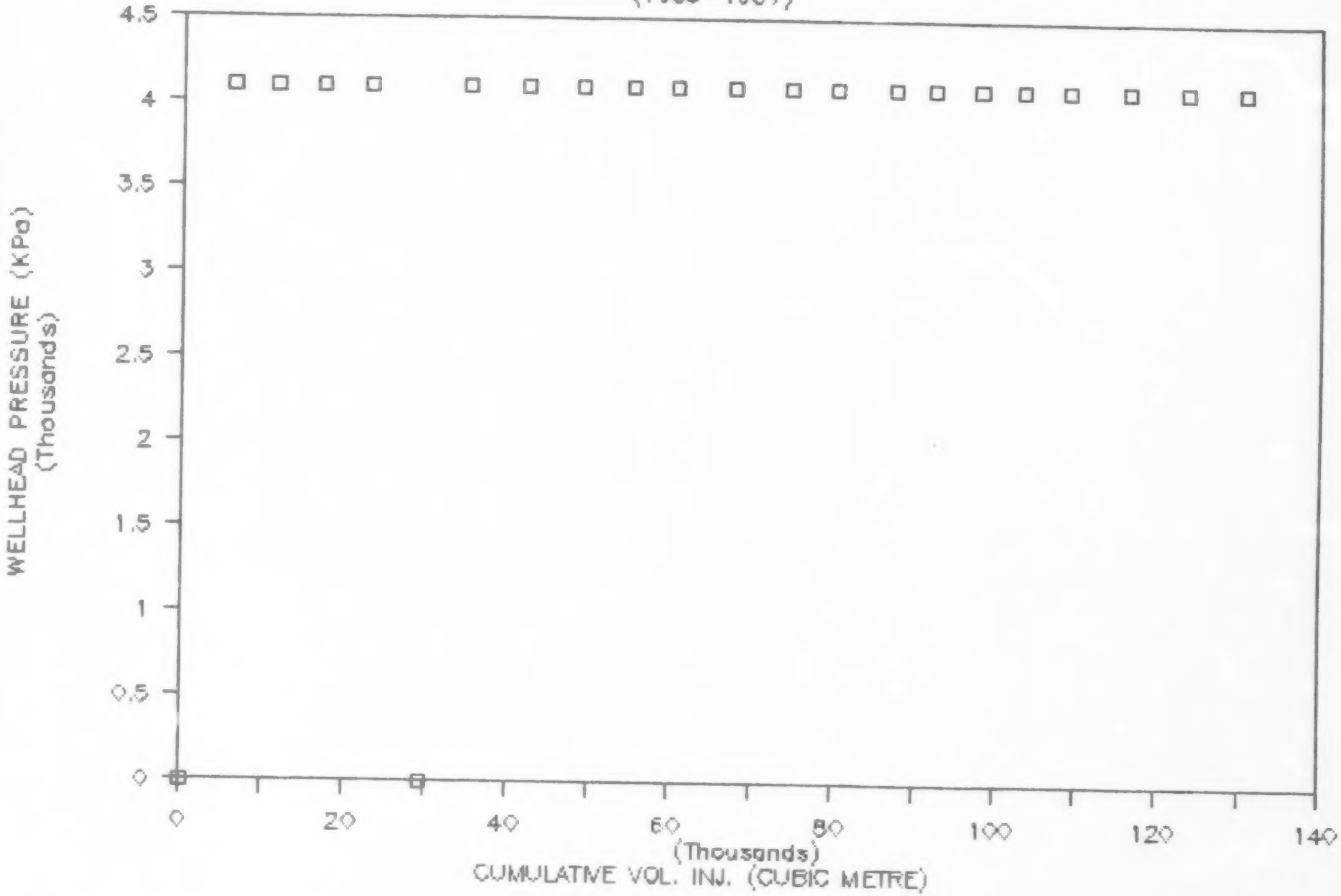

AMOCO ET AL WD-1 SUGDEN 6-4-63-8 W4M

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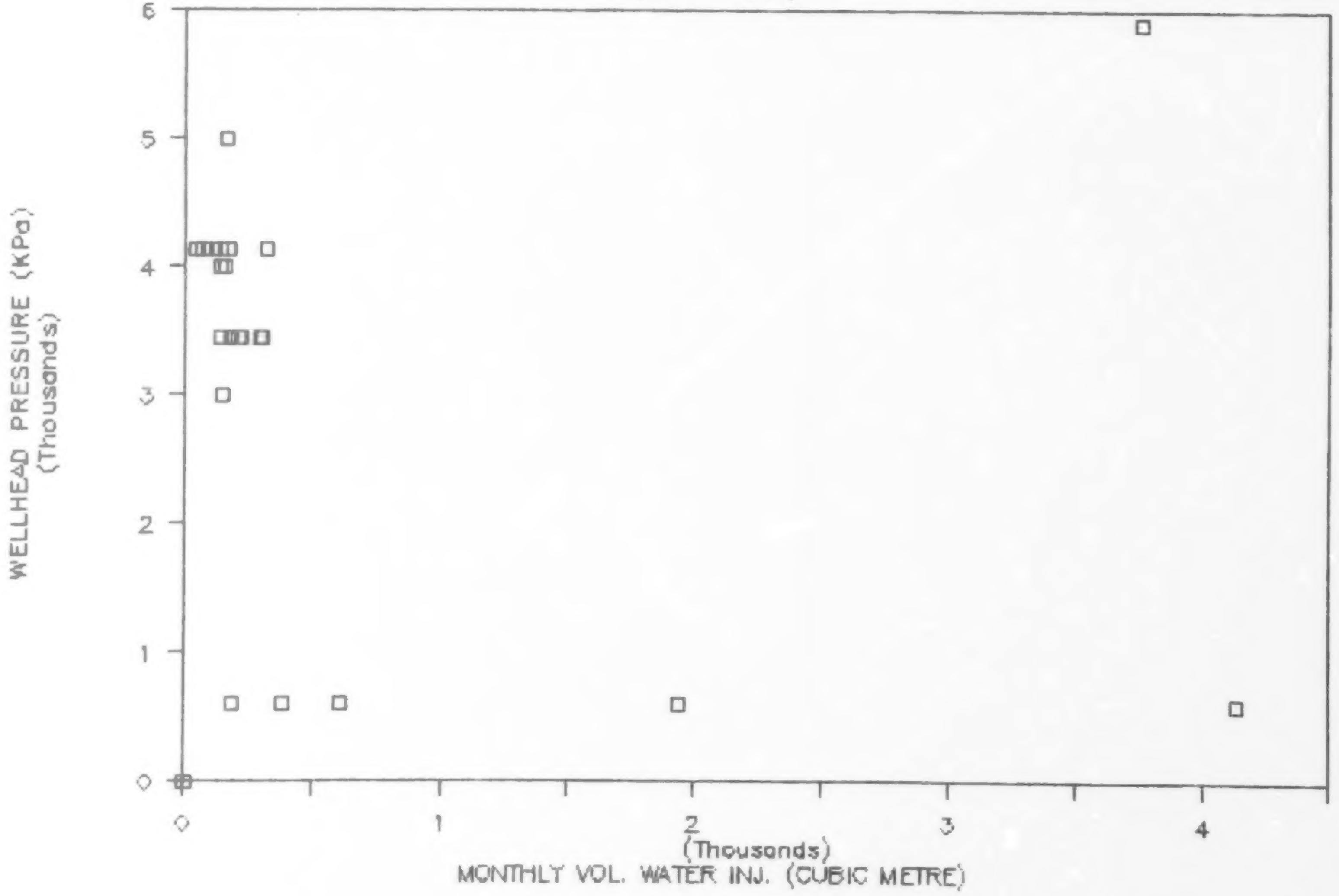

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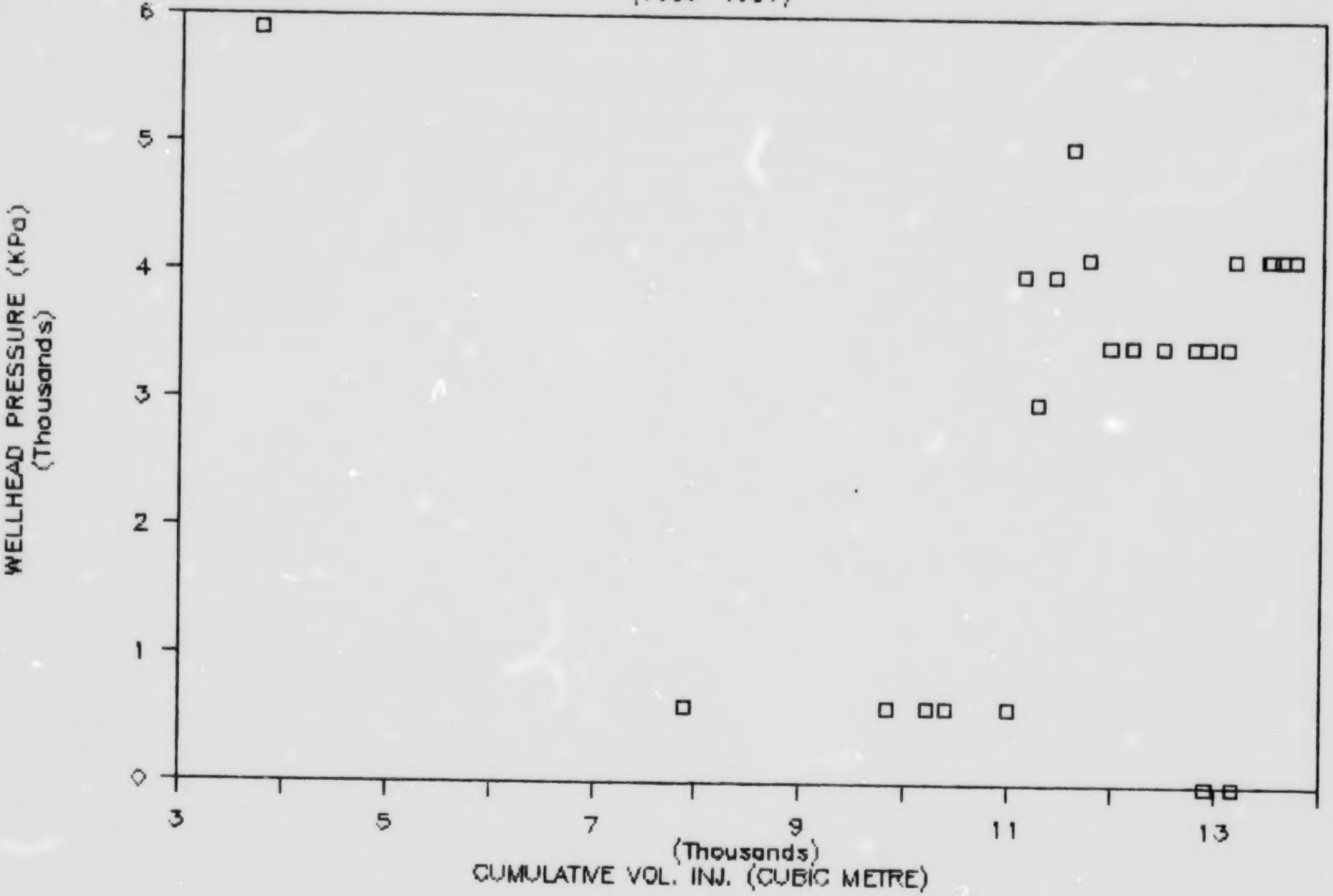
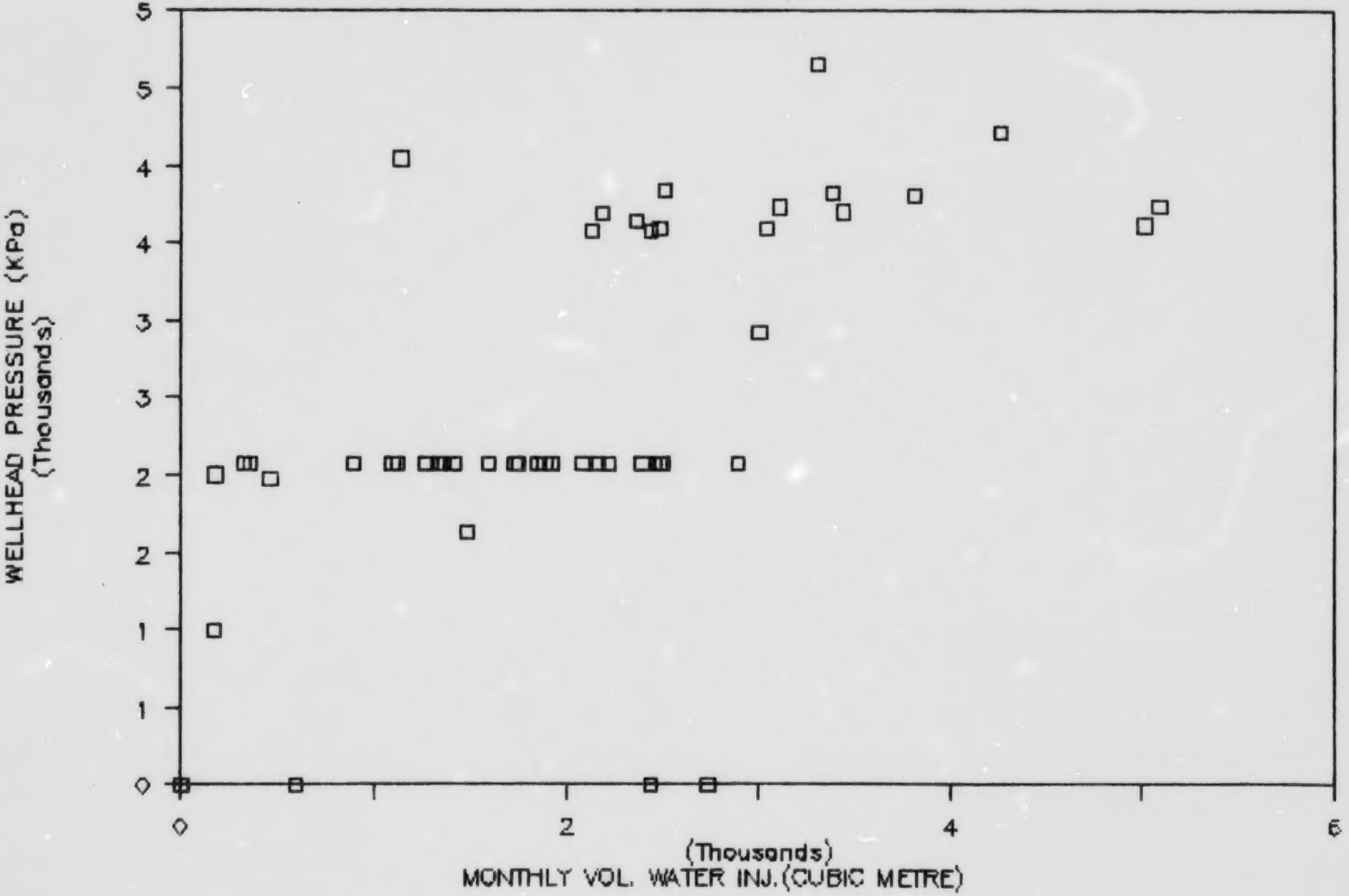
(1986-1987)



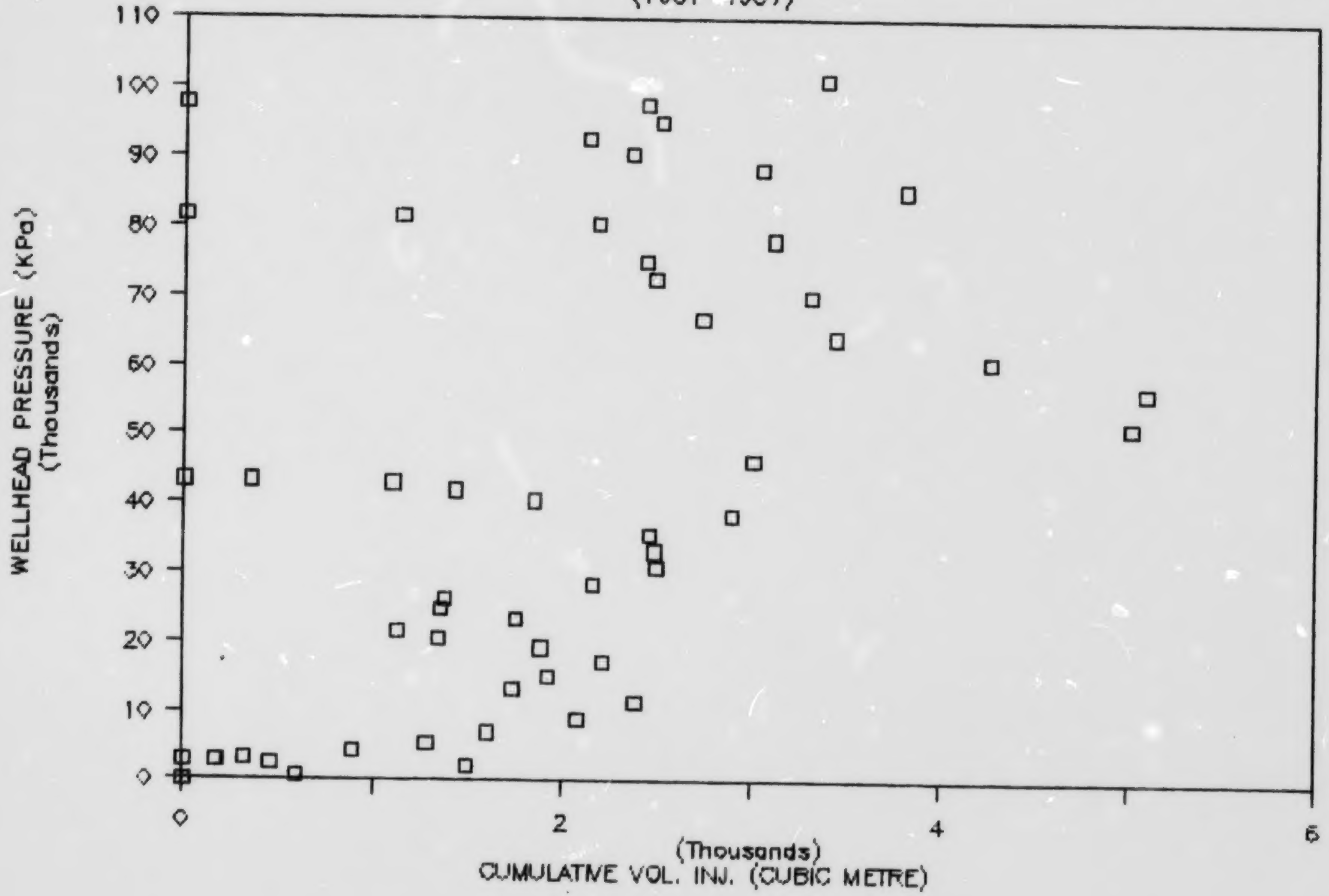
WESTCOAST MANATOKAN 10-12-63-8 W4M

(1981 – 1987)



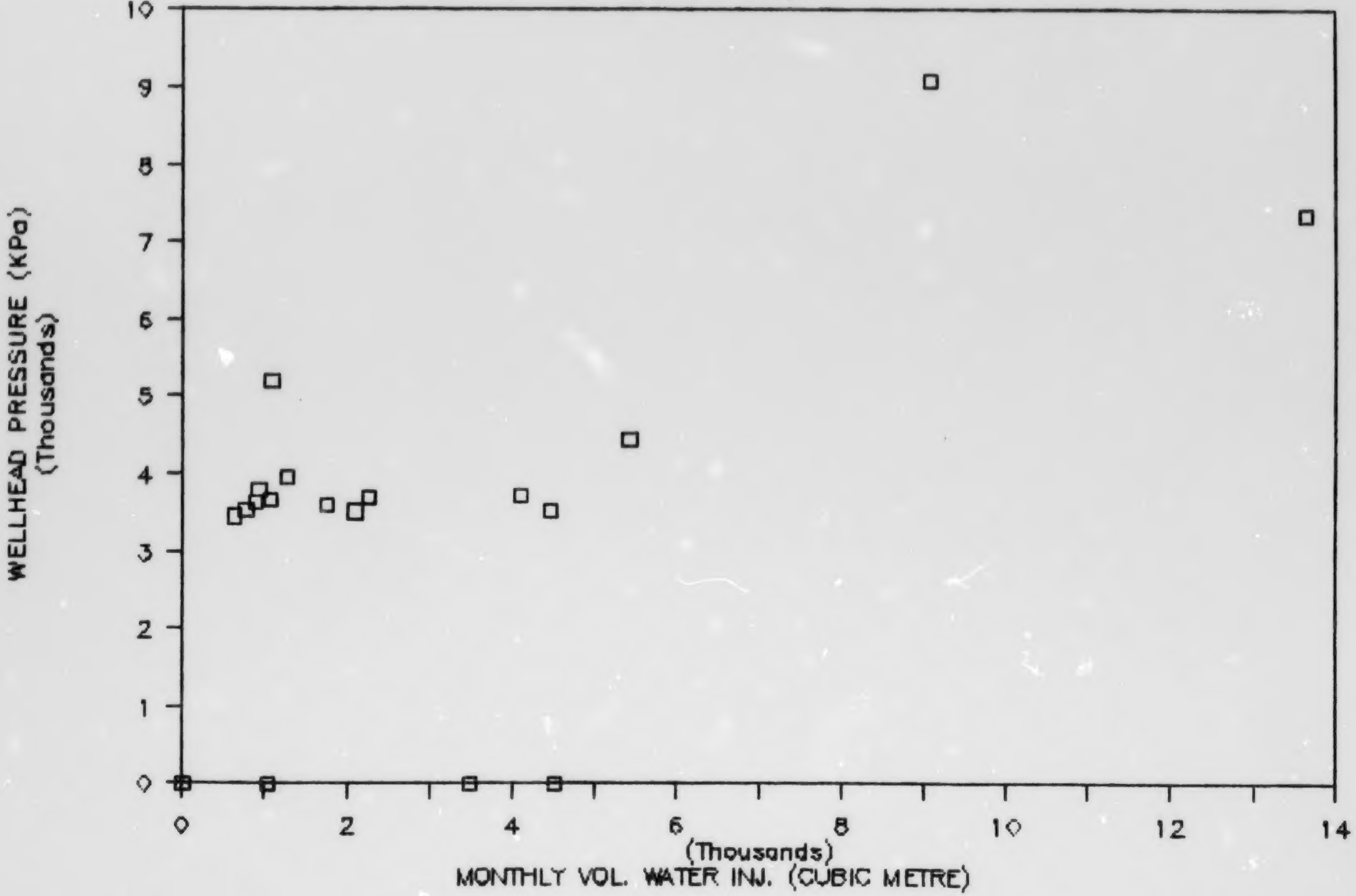
WESTCOAST MANATOKAN 10-12-63-8 W4M

(1981 - 1987)



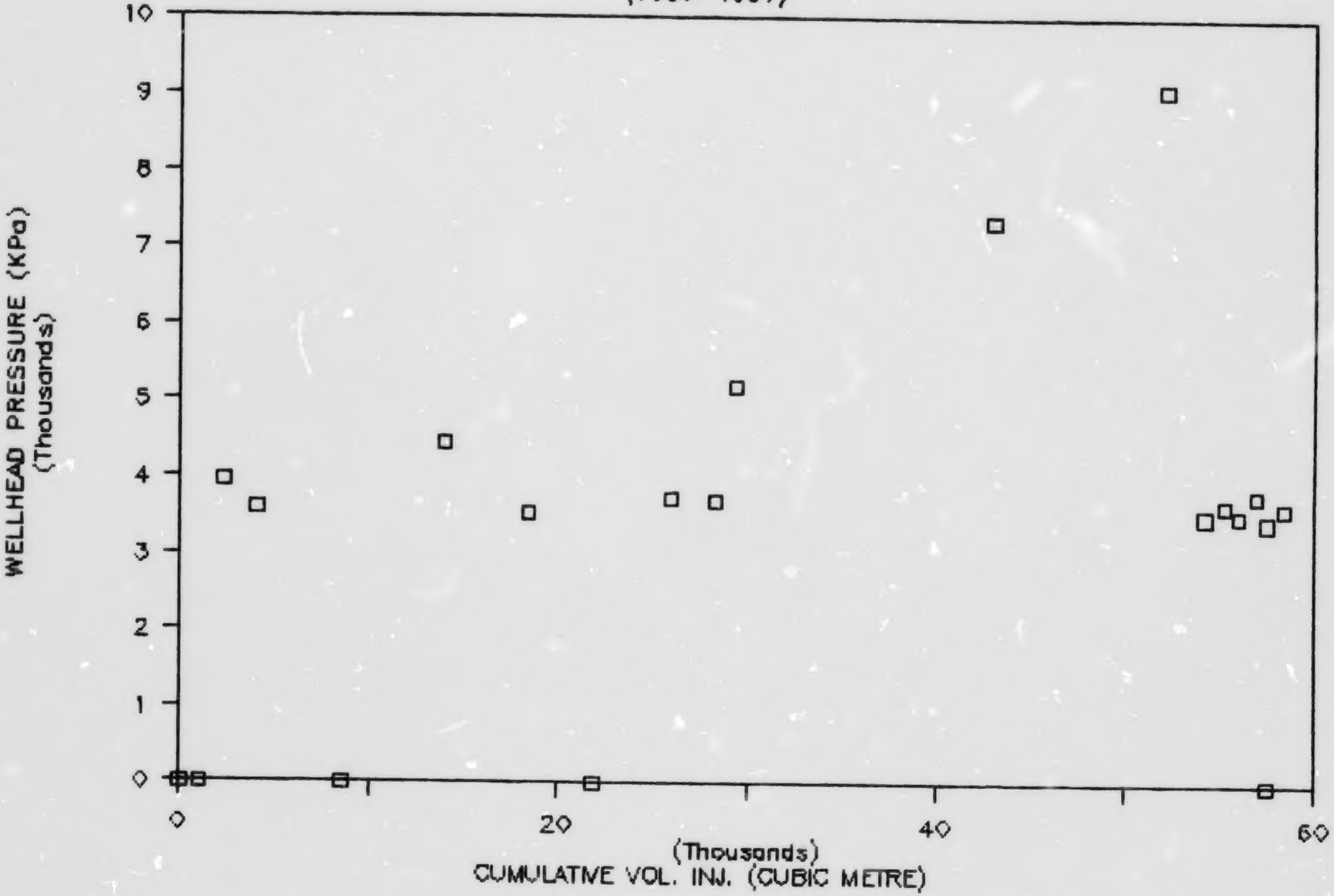
CDNOXY ET AL SWD WOLFLK 6-13-63-8 W4M

(1986-1987)



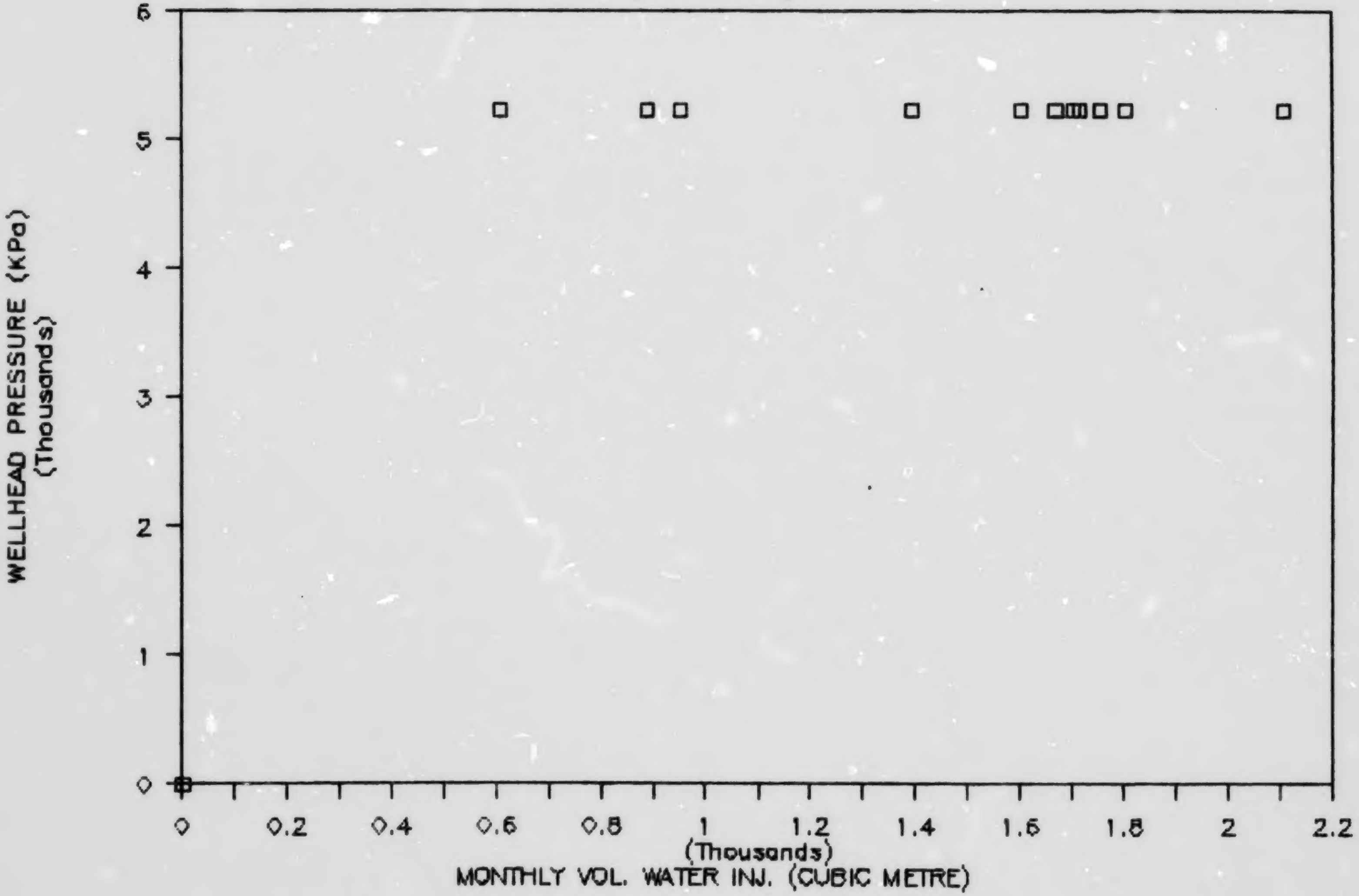
CDNOXY ET AL SWD WOLFLK 6-13-63-8 W4M

(1986-1987)



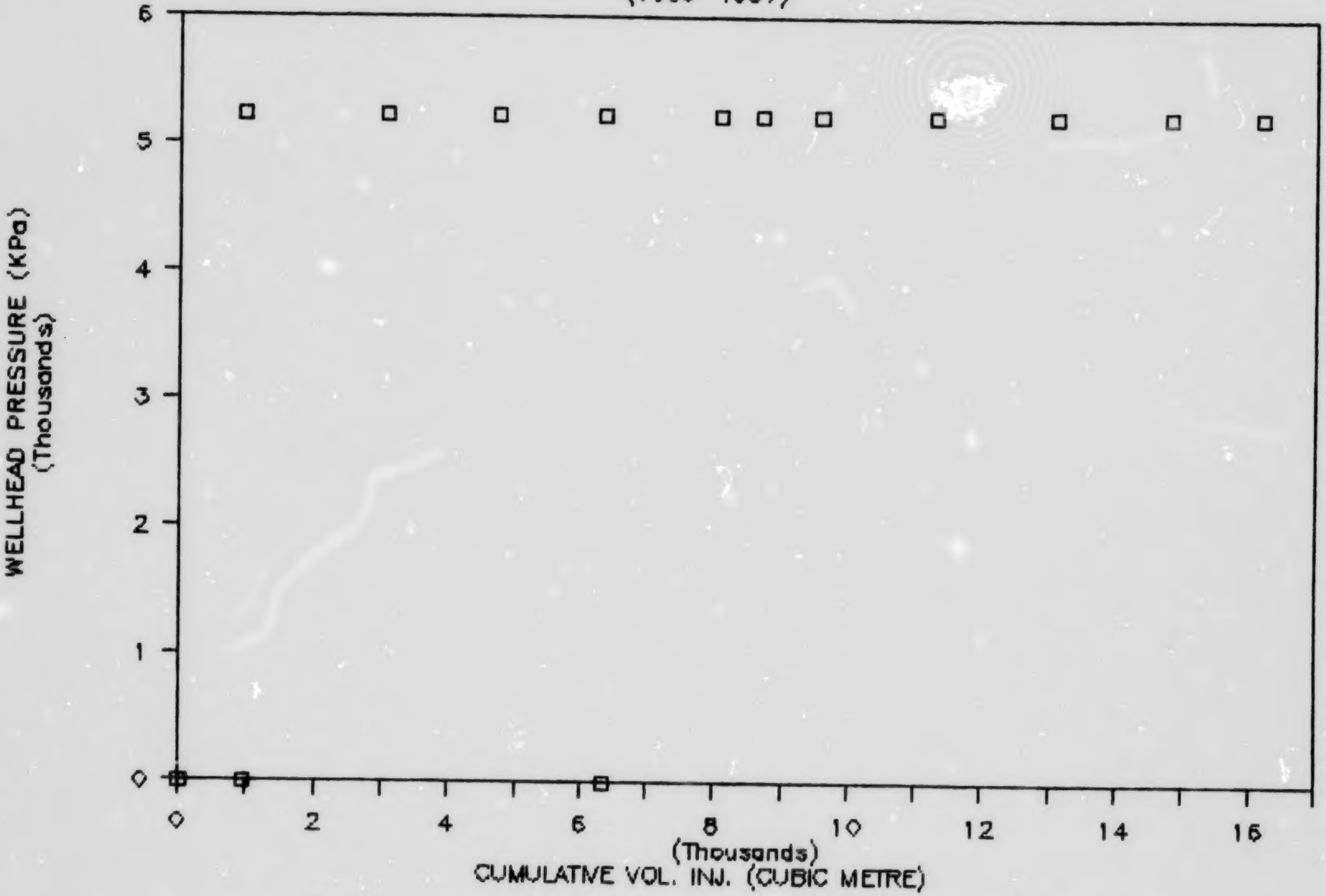
WINCAN ET AL CRAIGEND 11-33-63-11 W4M

(1986-1987)



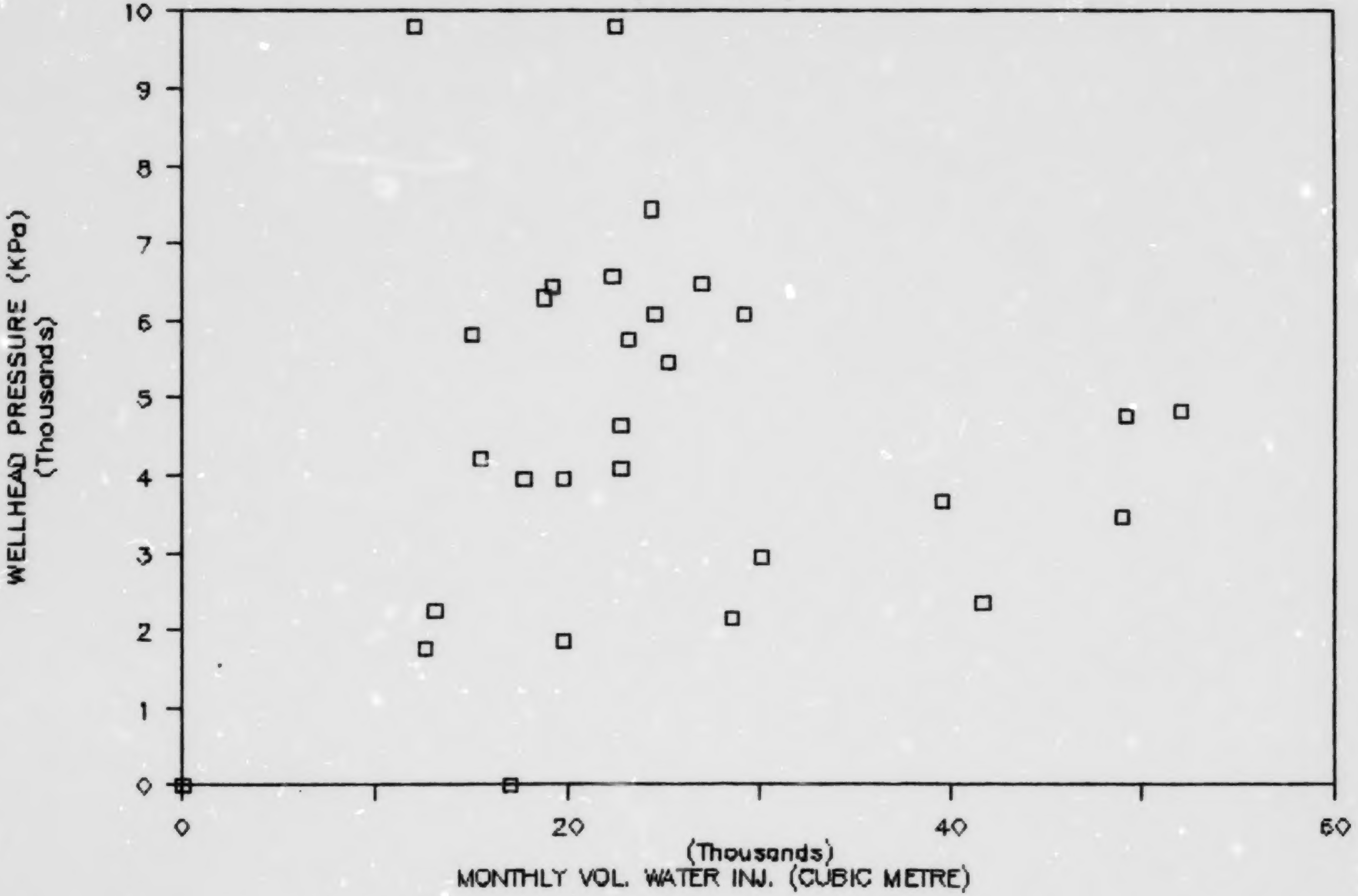
WINCAN ET AL CRAIGEND 11-33-63-11 W4M

(1986-1987)



ESSO 79 SWD COLDLK 7-18-64-3 W4M

(1985-1987)



ESSO 79 SWD COLDLK 7-18-64-3 W4M

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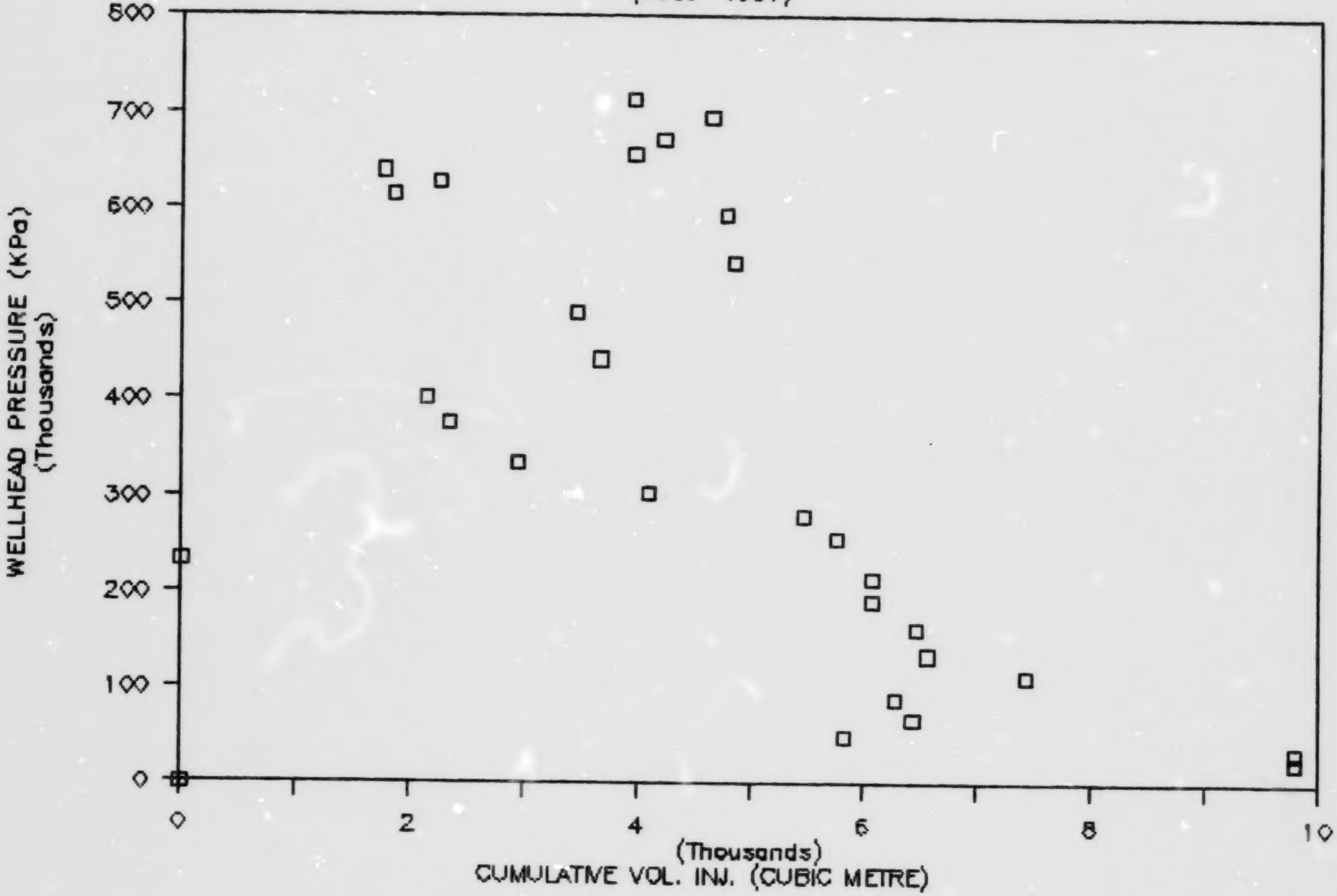

ESSO 85 SWD ETHELLK 1-19-64-3 W4M

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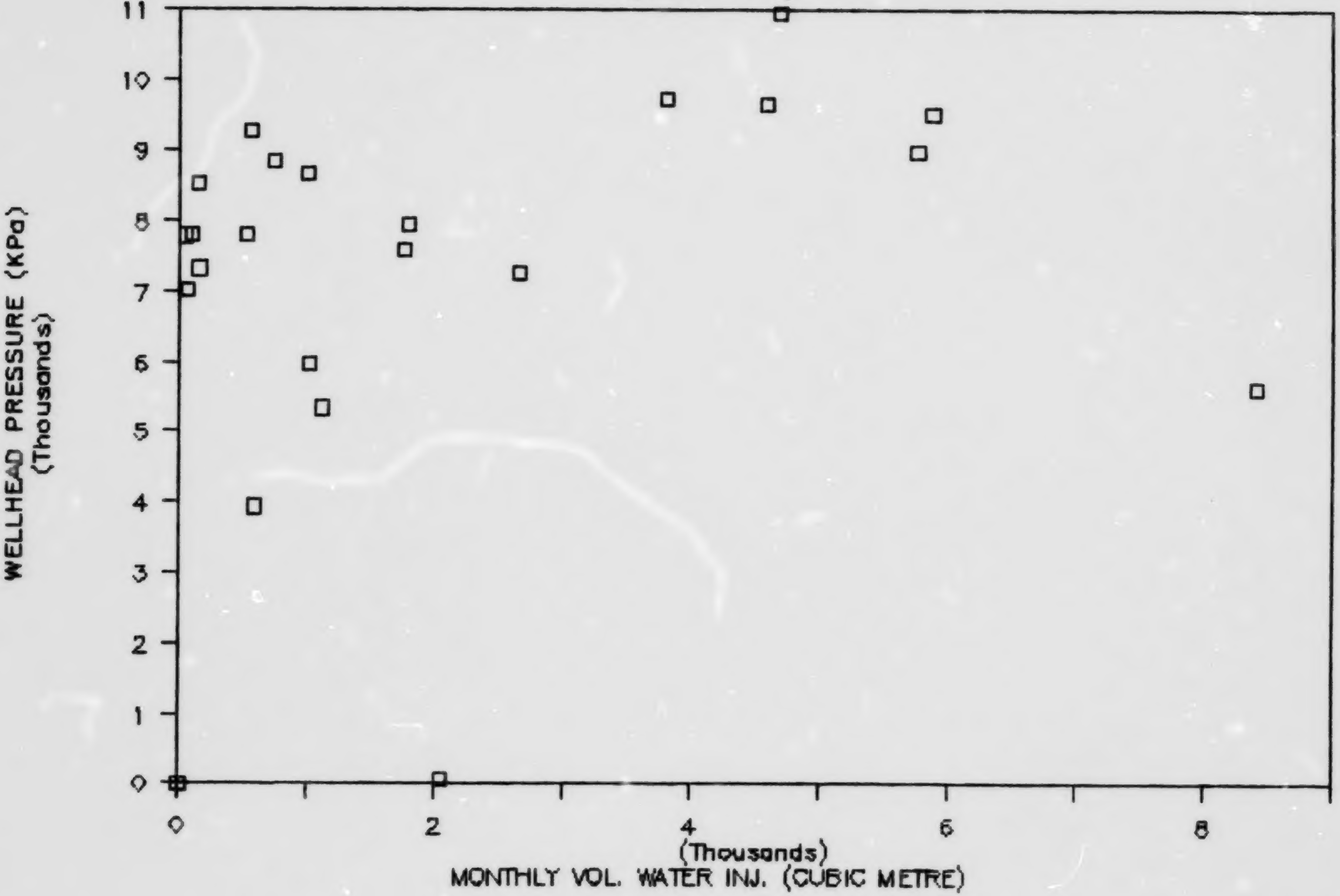

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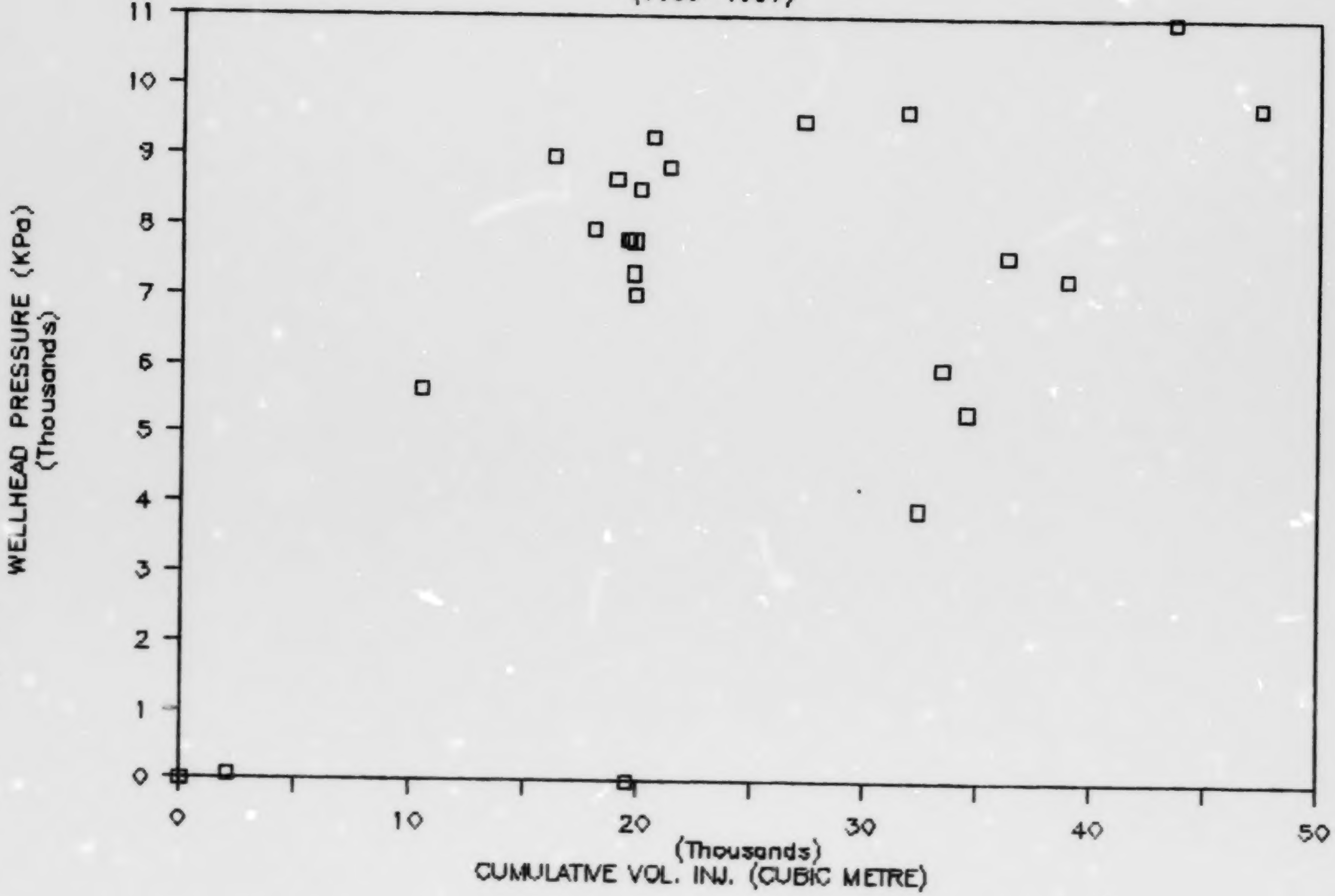
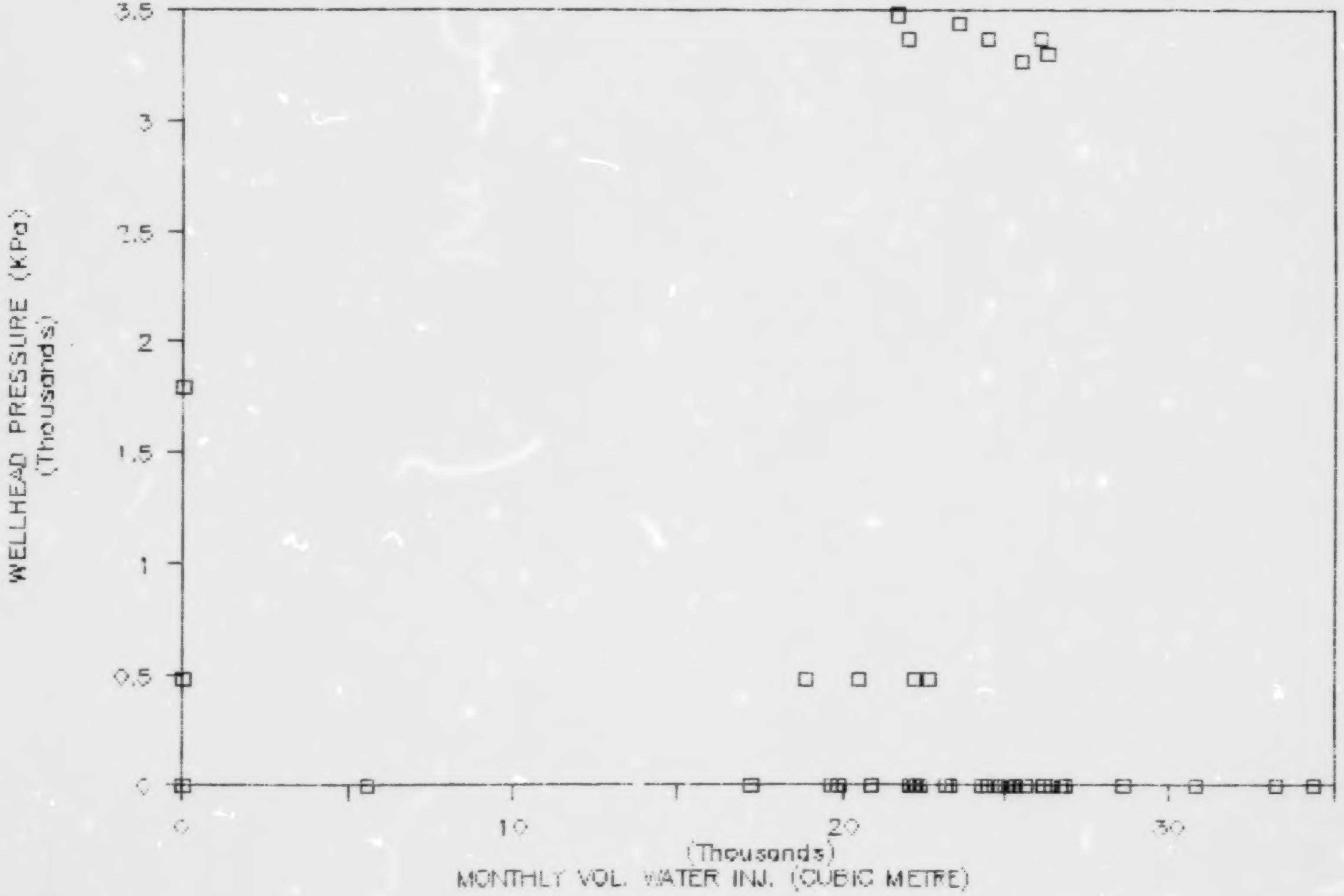


ESSO ETHELLK SWD 10-22-64-3 W4M

(1982-1985)



ESSO ETHEL LK SWD 10-22-64-3 W4M

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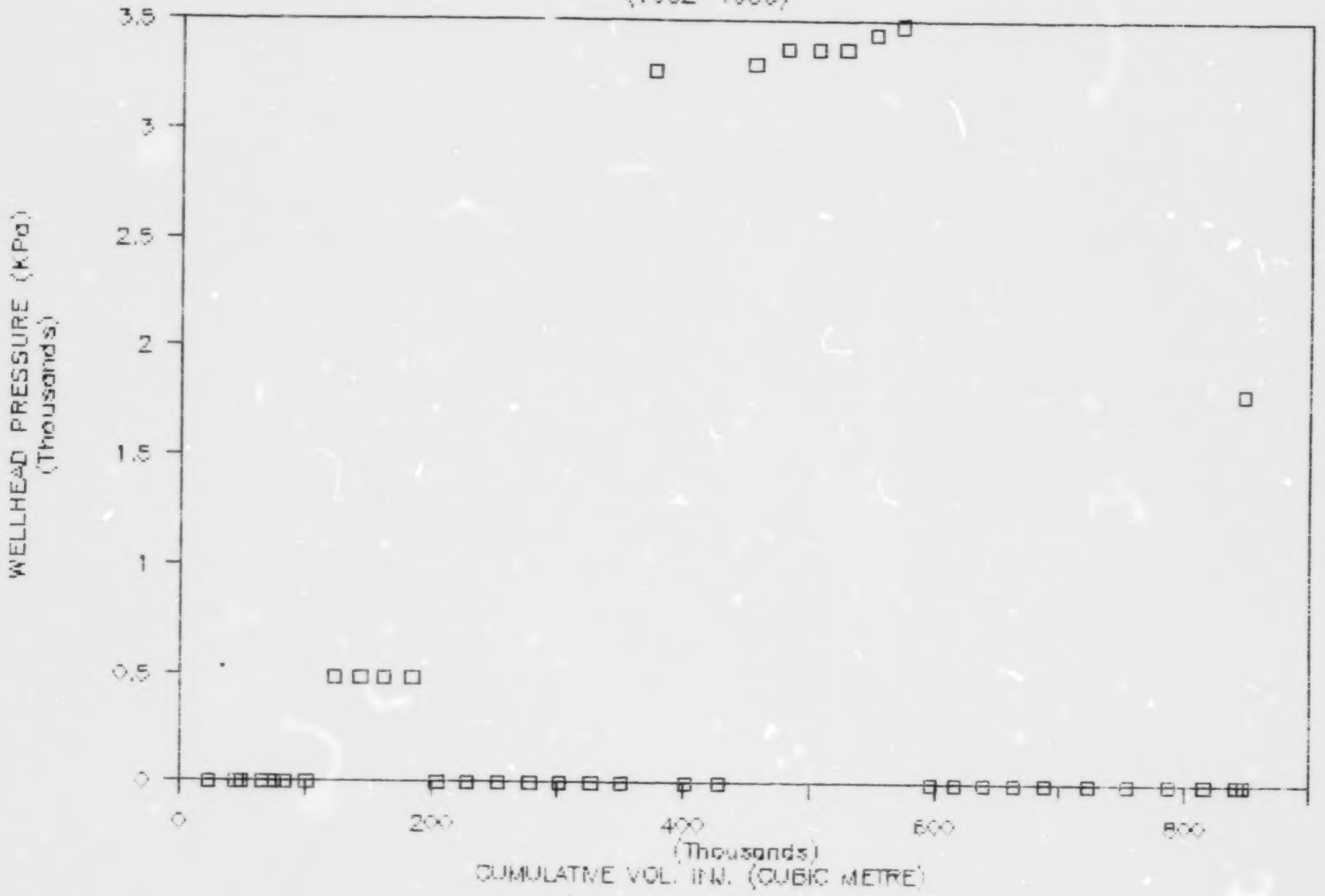

ESSO 83 SWD ETHELLK 1-32-64-3 W4M

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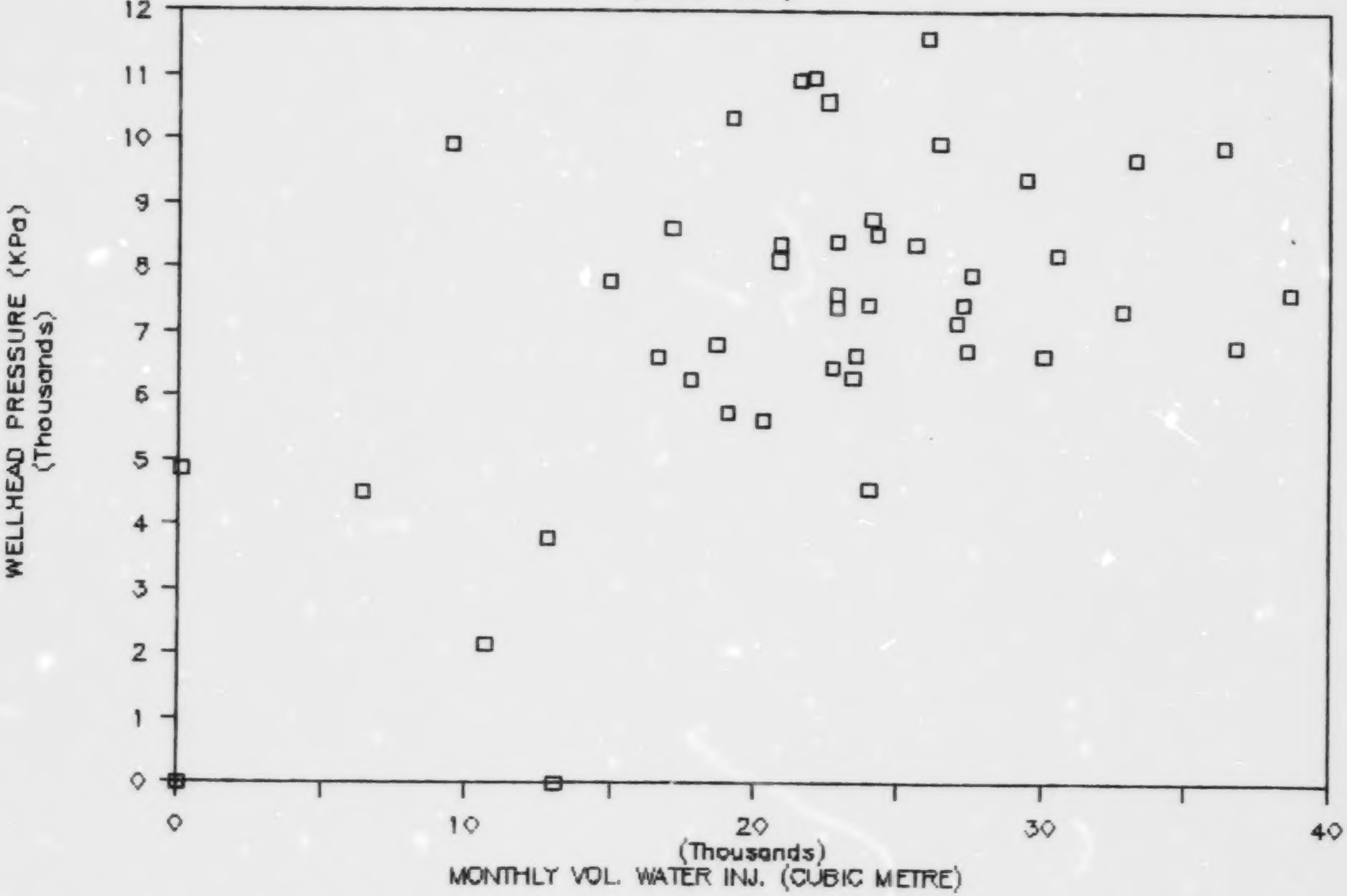

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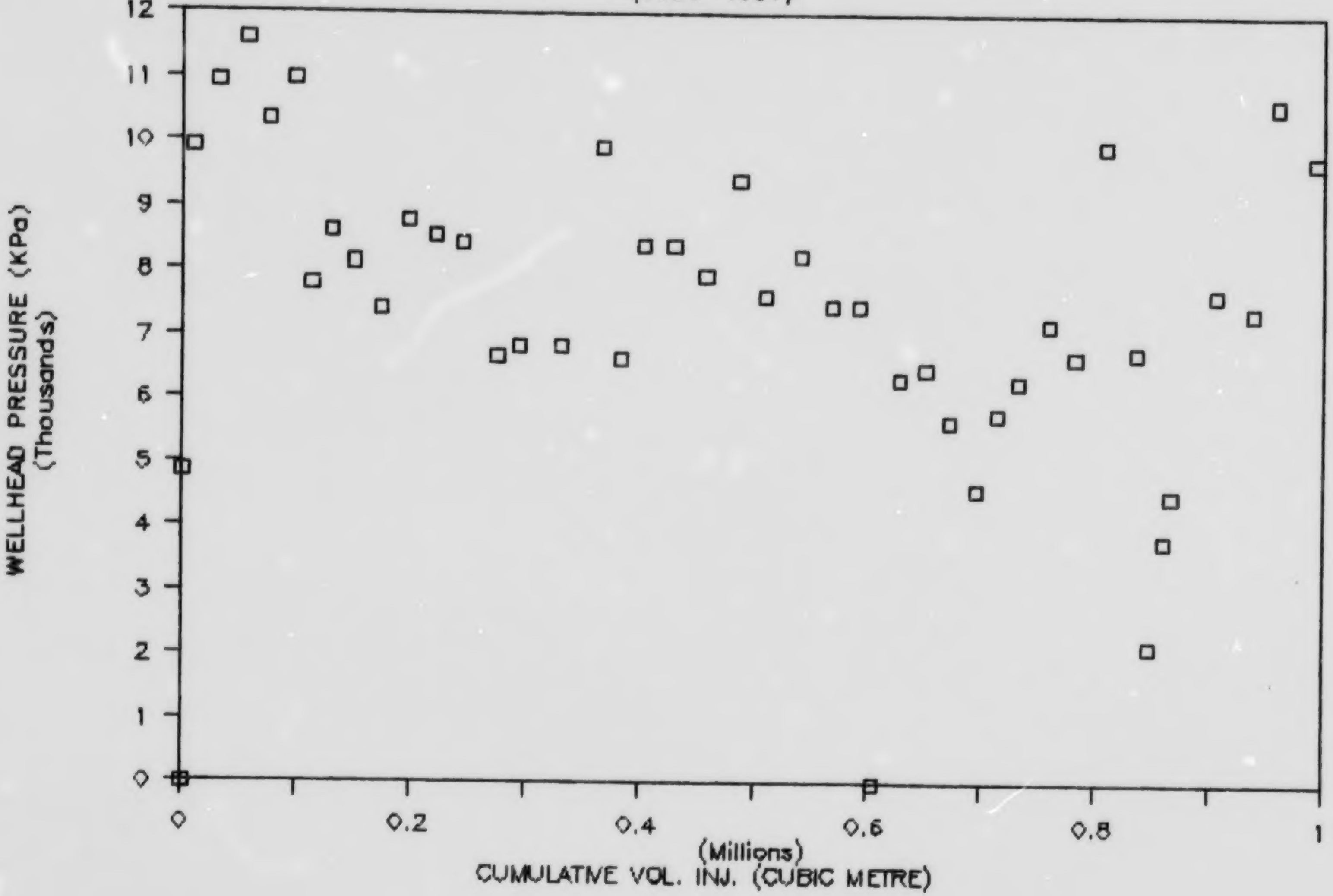

ESSO 83 INJ ETHELLK 8-33-64-3 W4M

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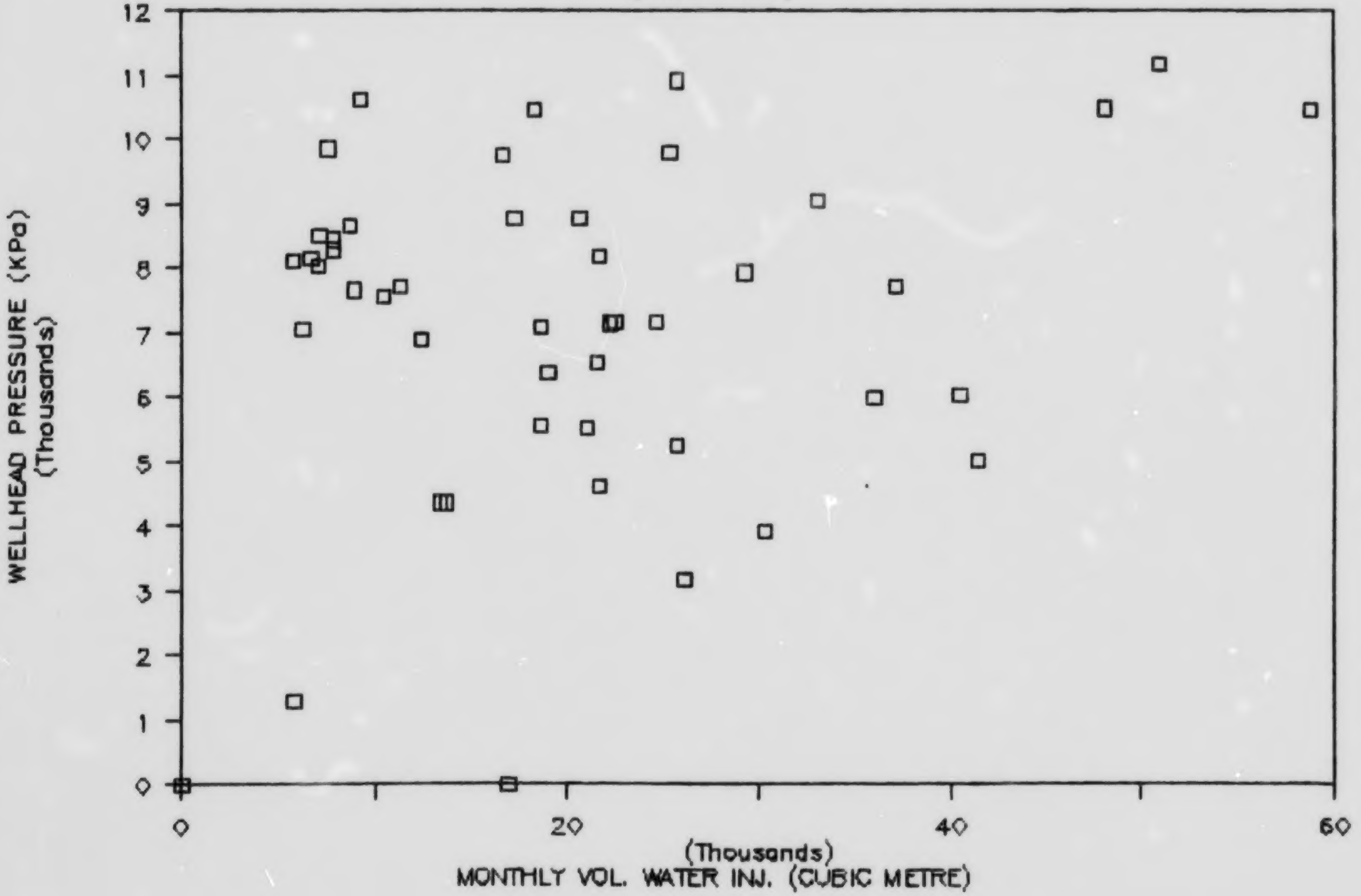
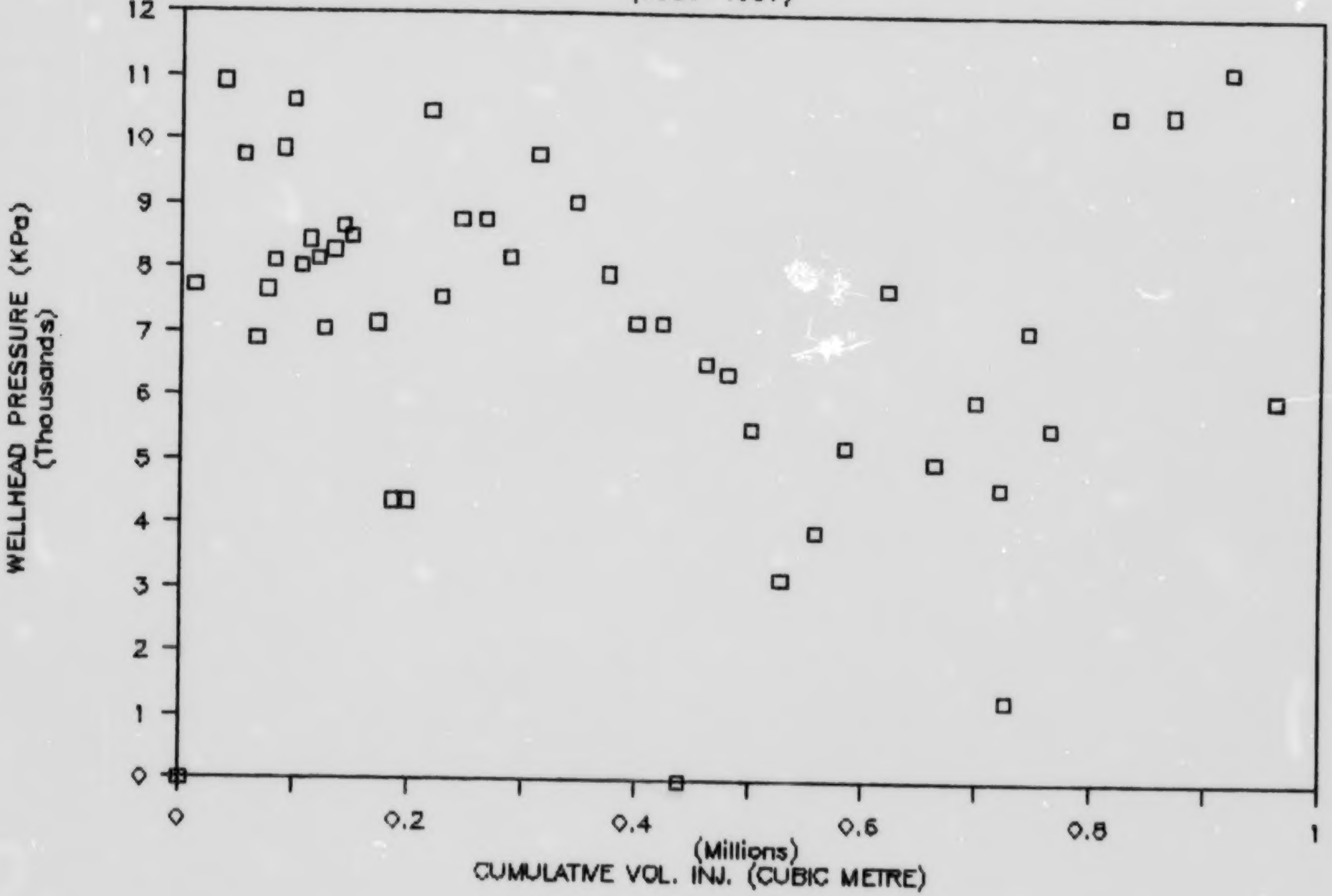


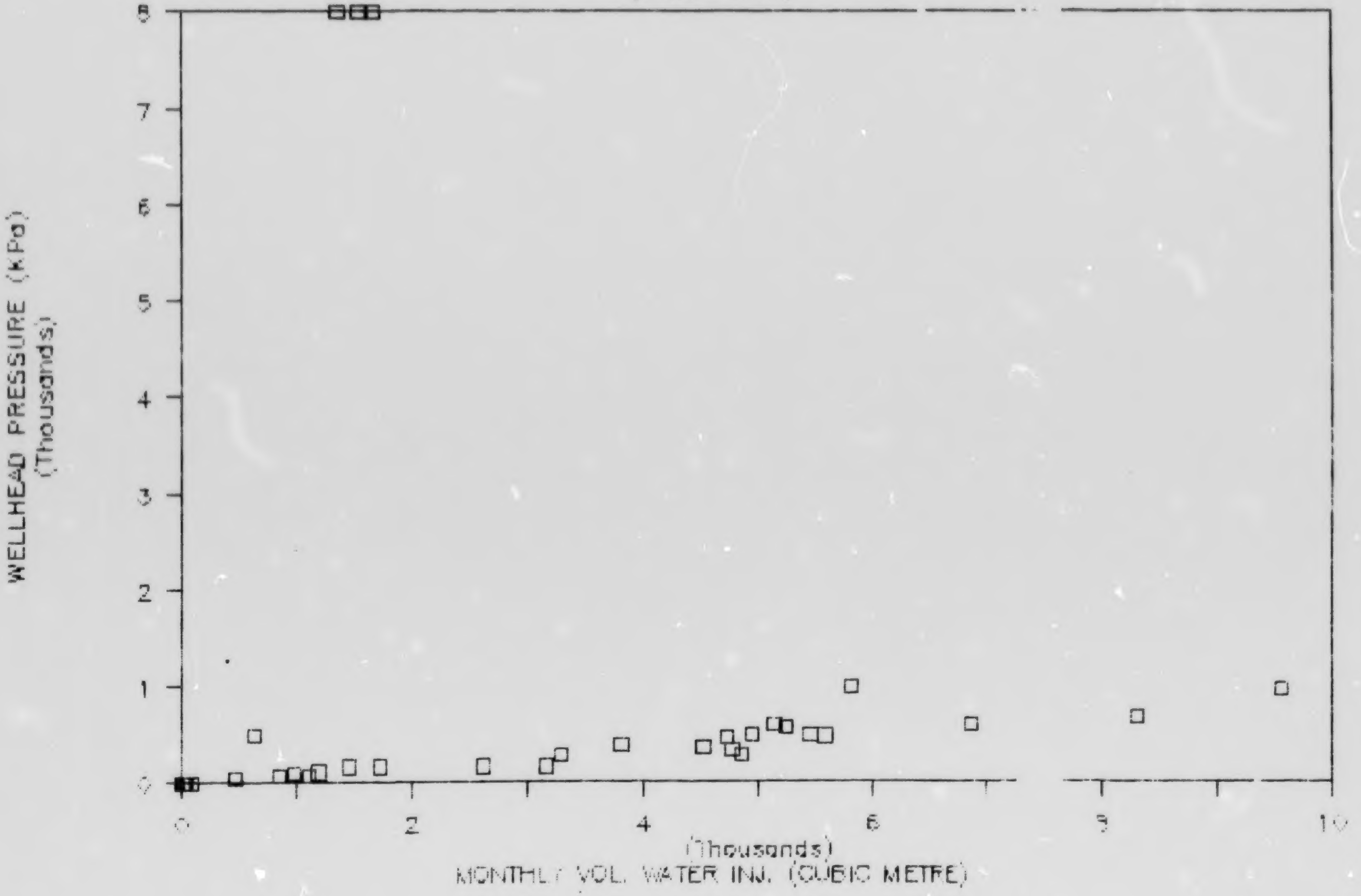
ESSO 83 INJ ETHELLK 8-33-64-3 W4M

(1984-1987)



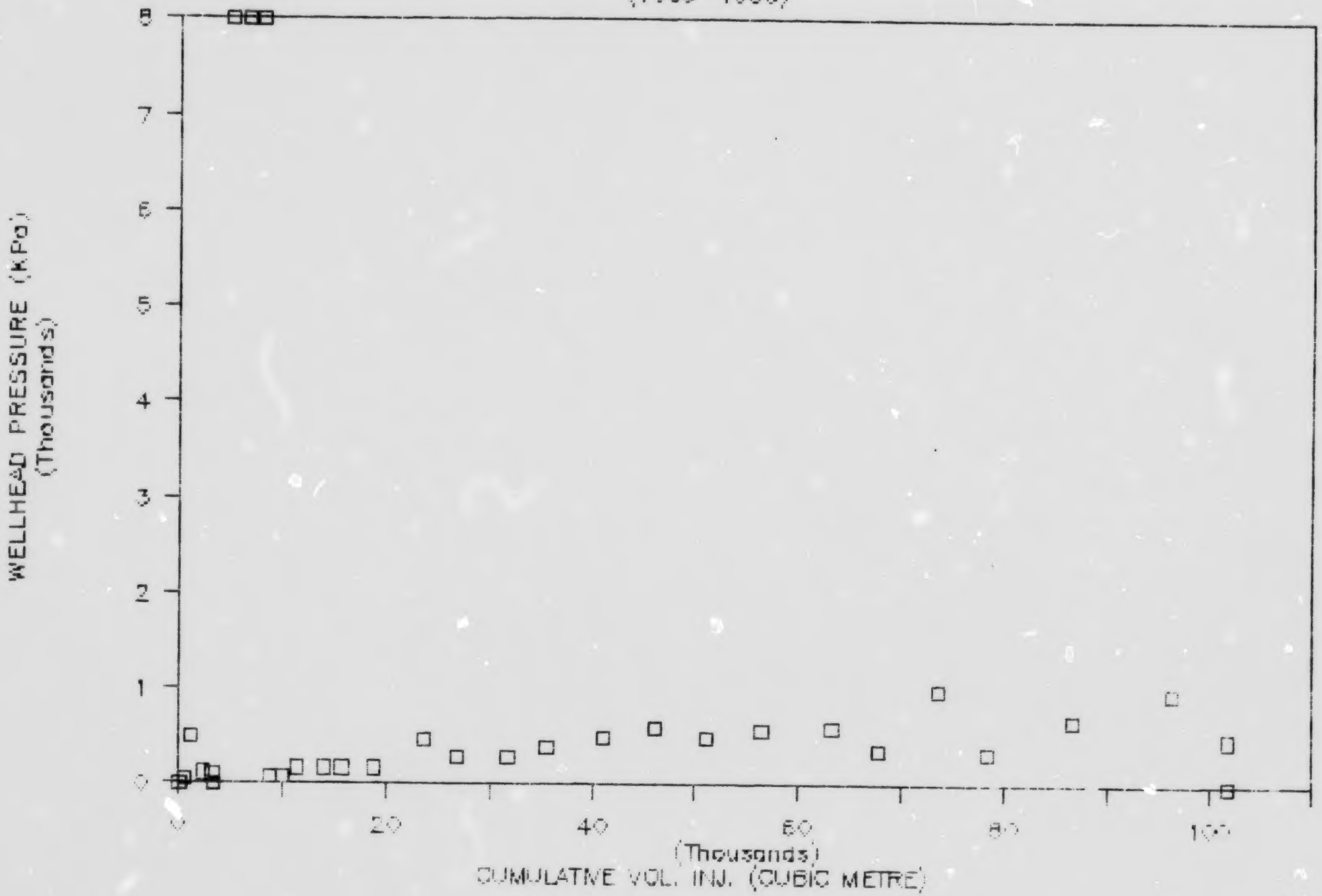
MOBIL GARTH 12-6-64-6 W4V

(1983–1985)



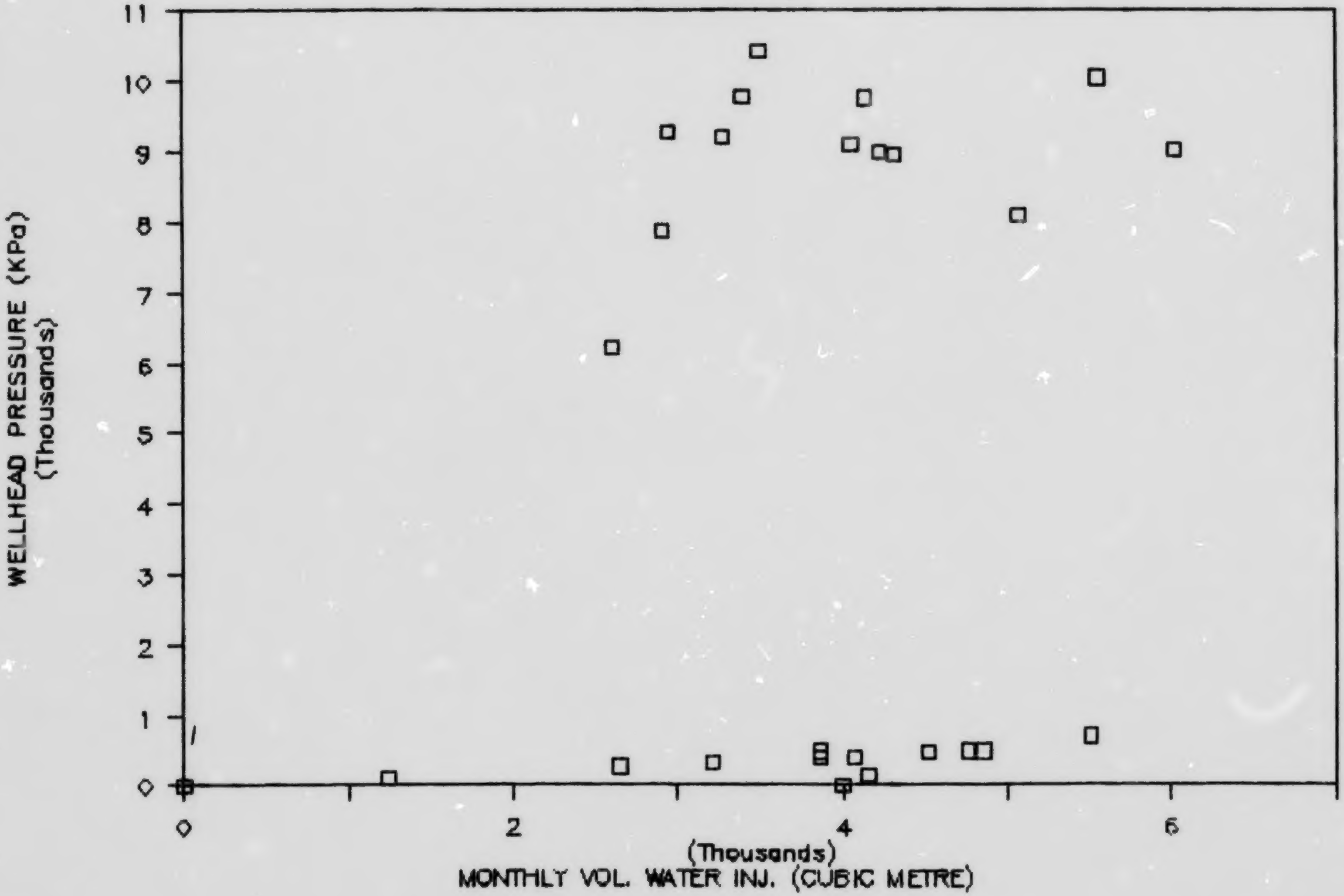
MOBIL GARTH 12-6-64-6 W4M

(1983–1985)



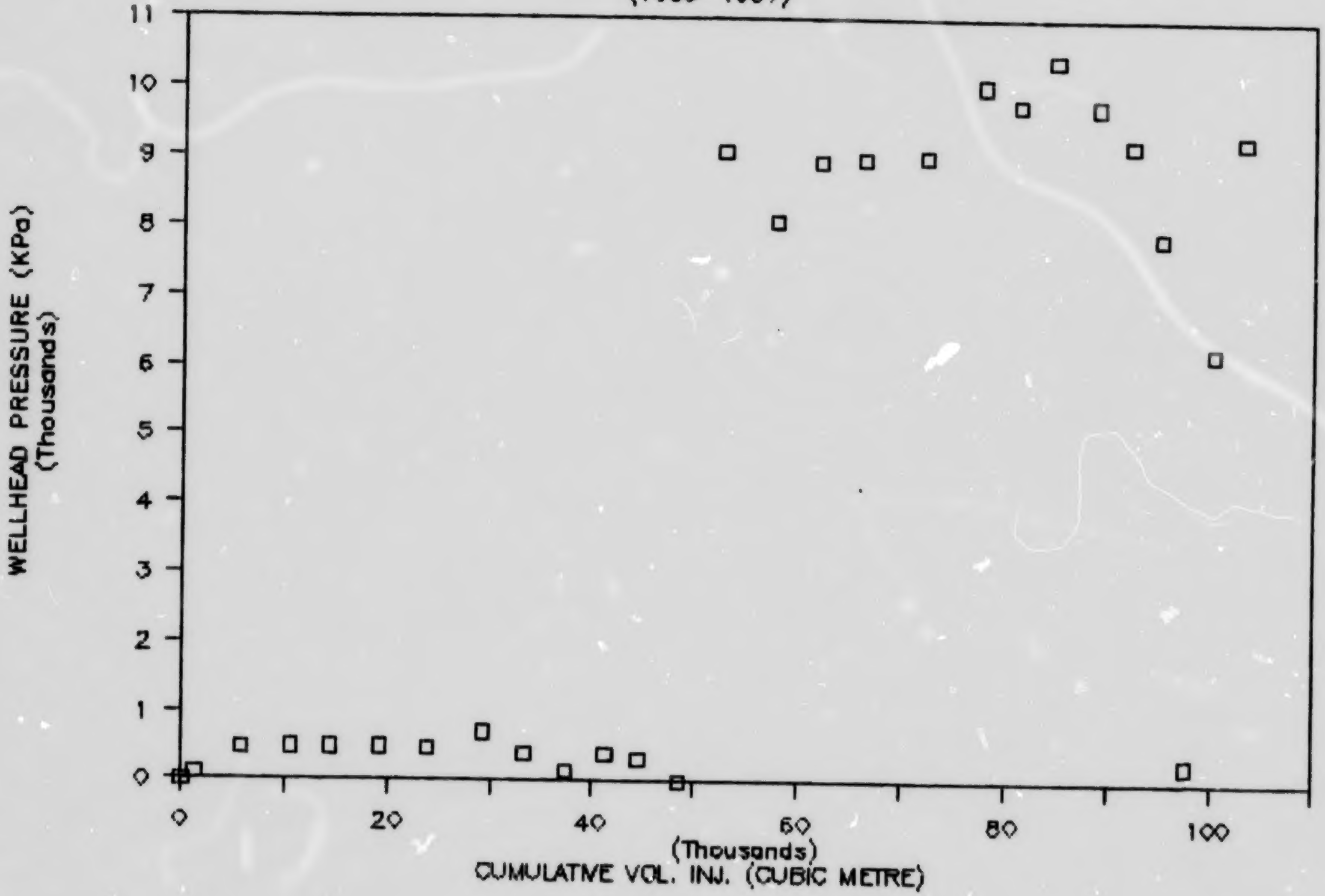
MOBIL GARTH 12-6-64-6 W4M

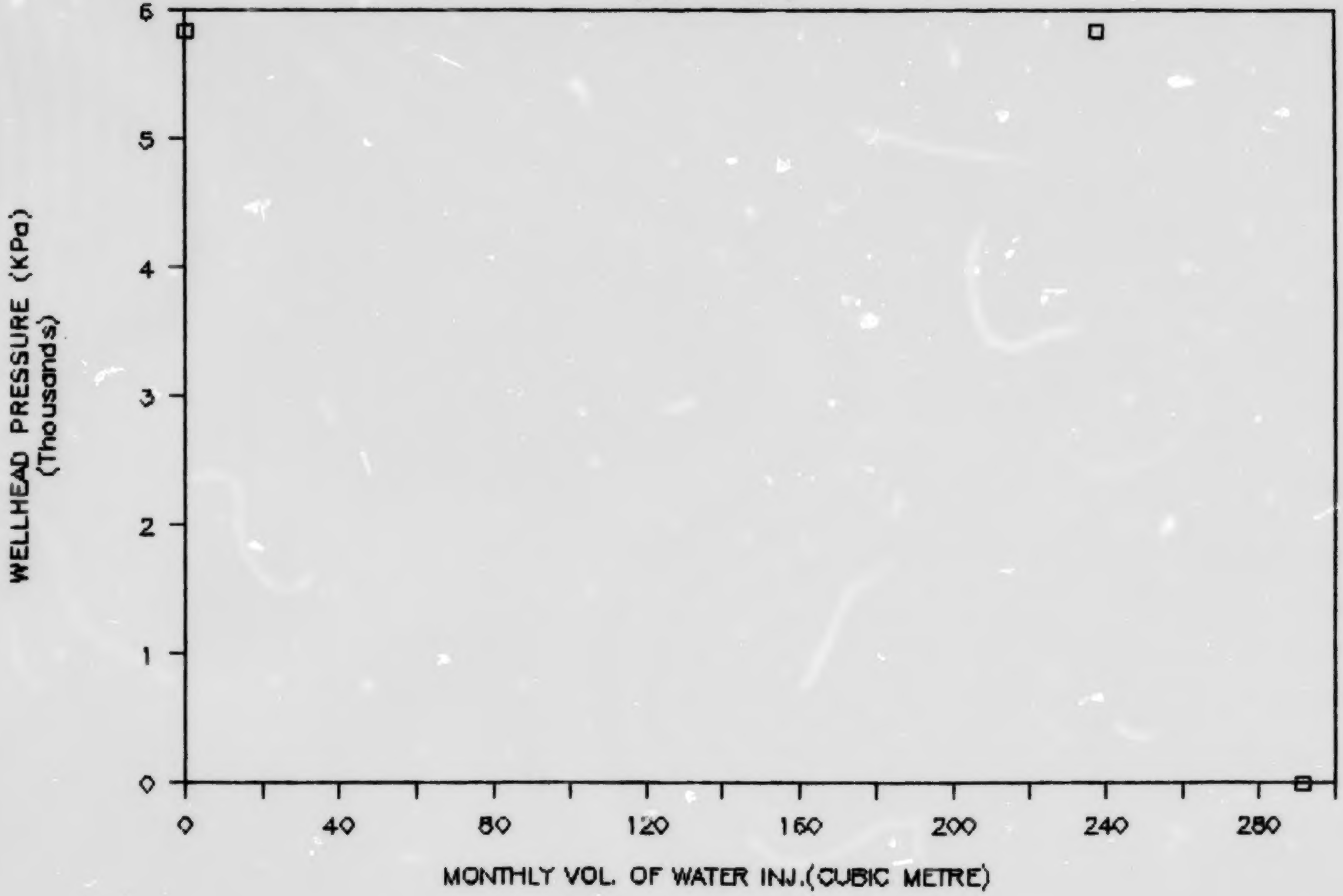
(1985–1987)



MOBIL GARTH 12-6-64-6 W4M

(1985–1987)



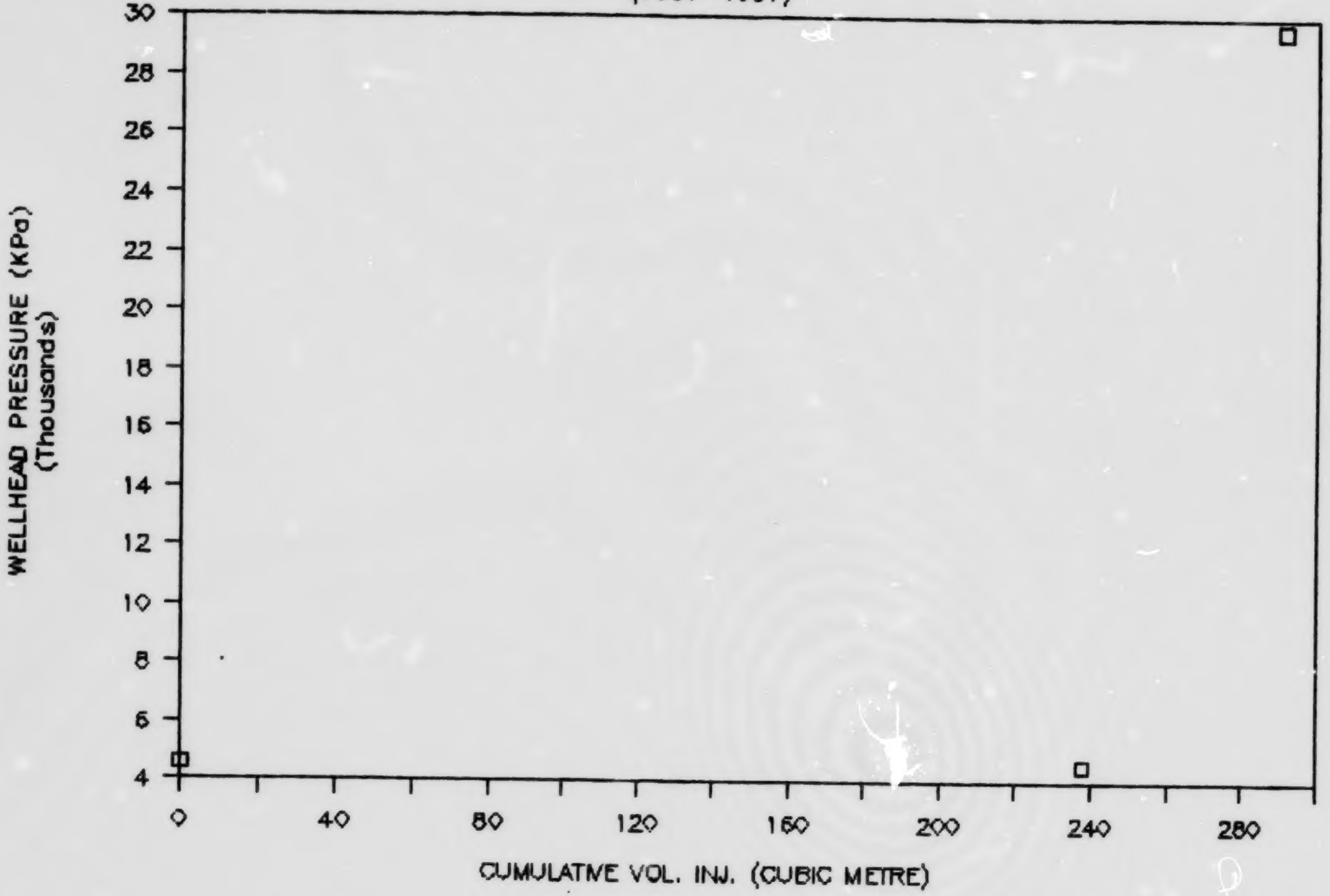


PUBCO CRAIGEND 10-1-64-13 W4M

(1981 – 1987)

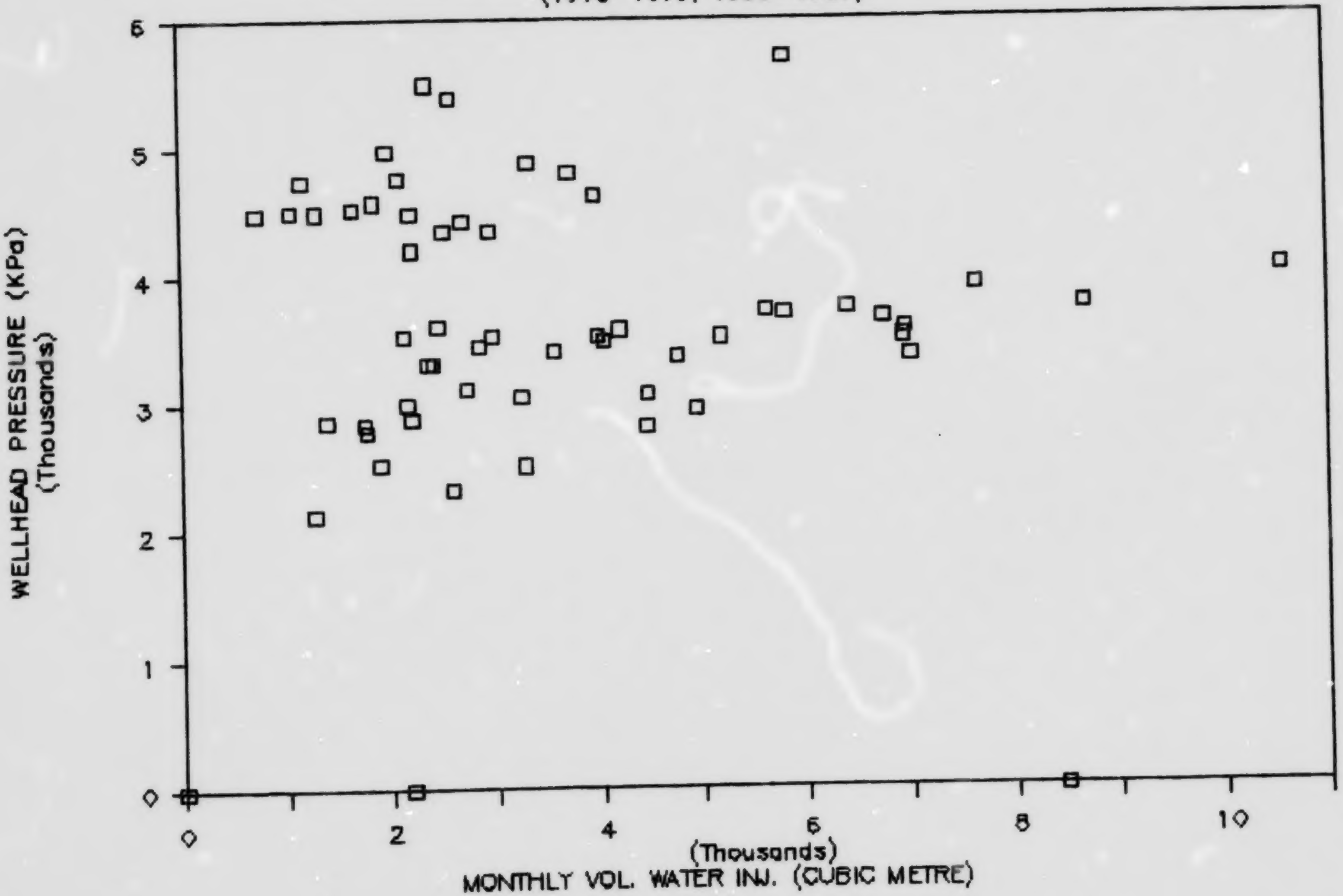
PUBCO CRAIGEND 10-1-64-13 W4M

(1981 – 1987)



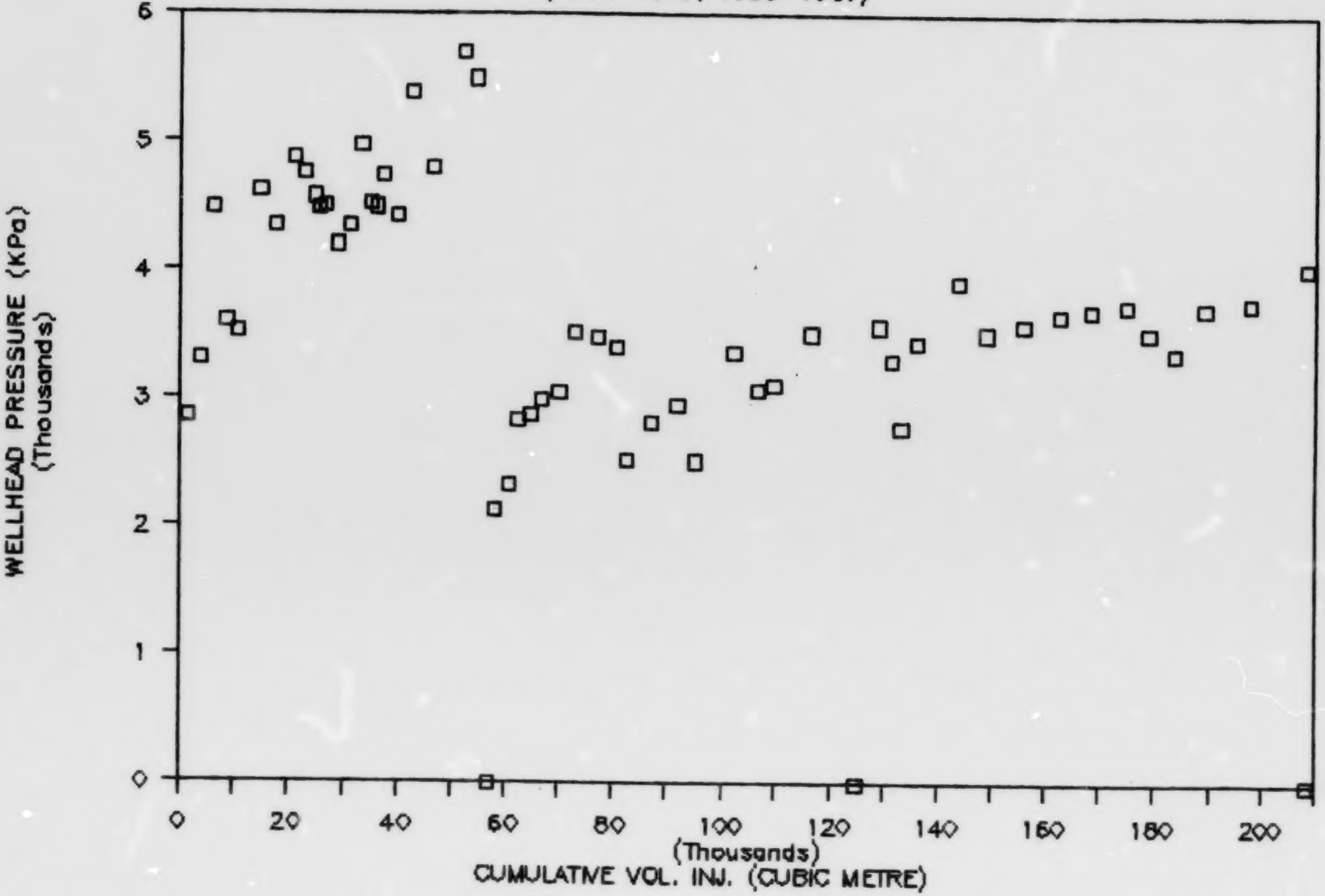
GULF COLD LAKE 1-14-65-2 W4M

(1978-1979, 1985-1987)



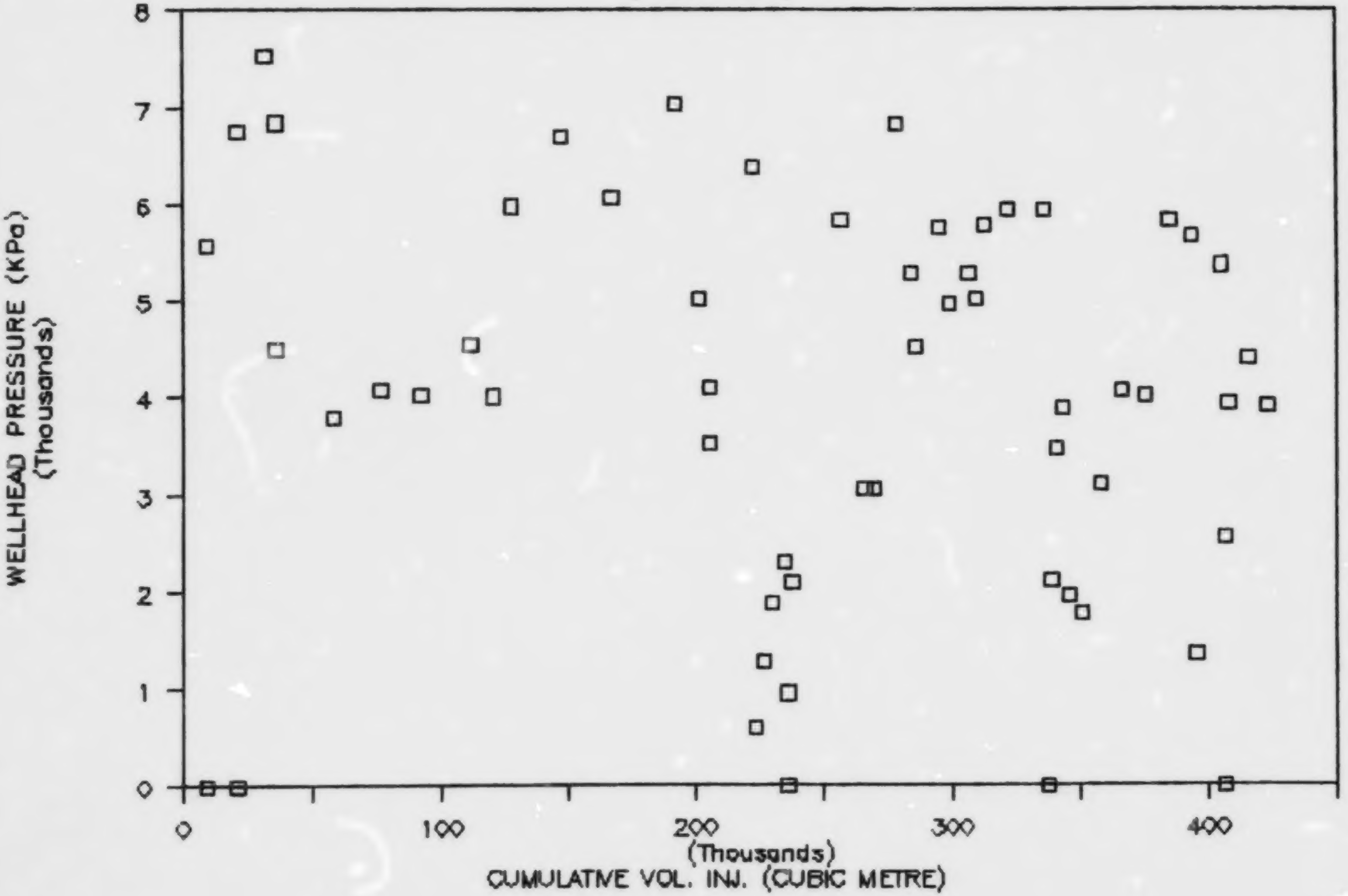
GULF COLD LAKE 1-14-65-2 W4M

(1978-1979, 1985-1987)



ESSO SWD LEMING ETHELLK 3-4-65-3 W4M

(1983–1987)



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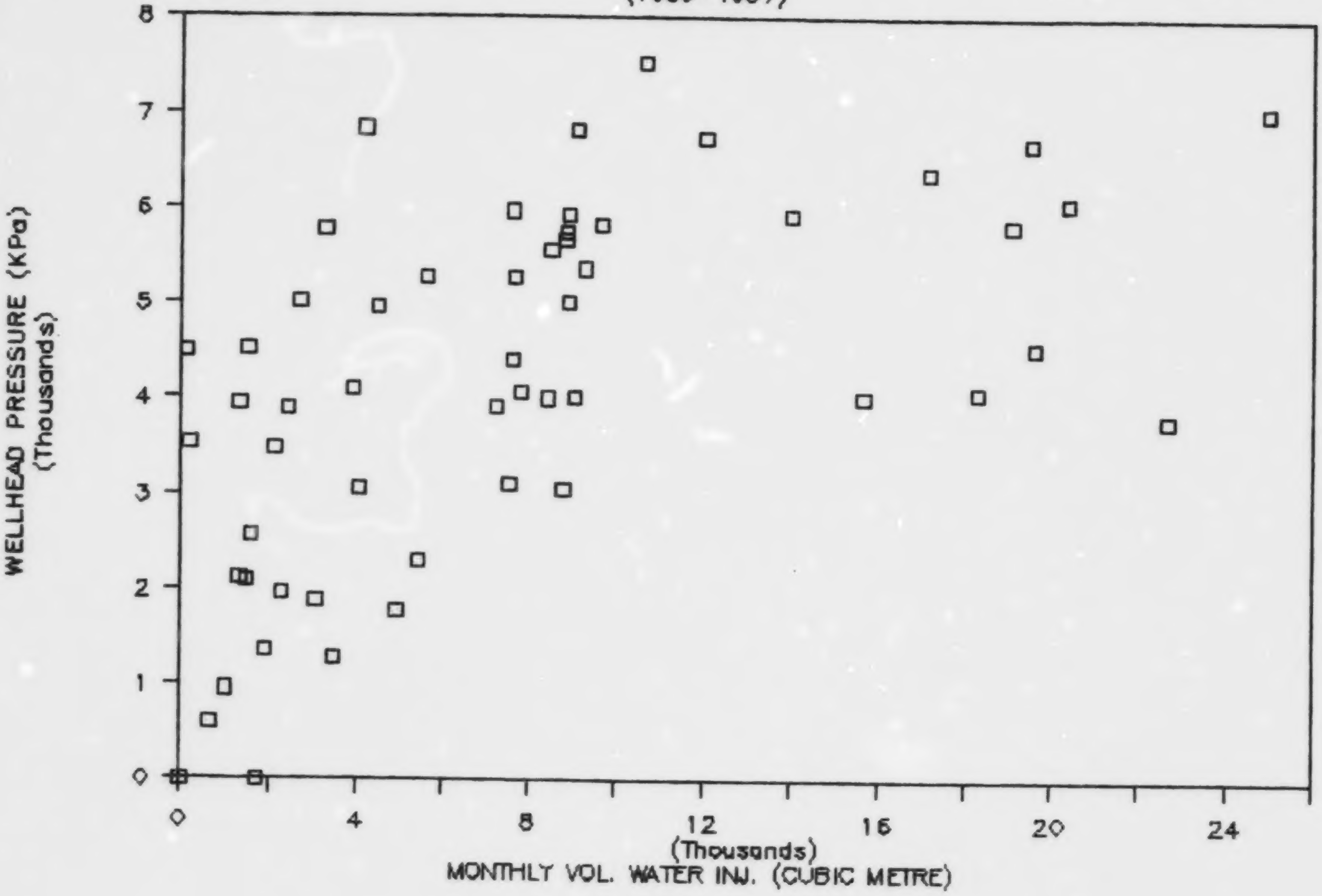
(1983-1987)



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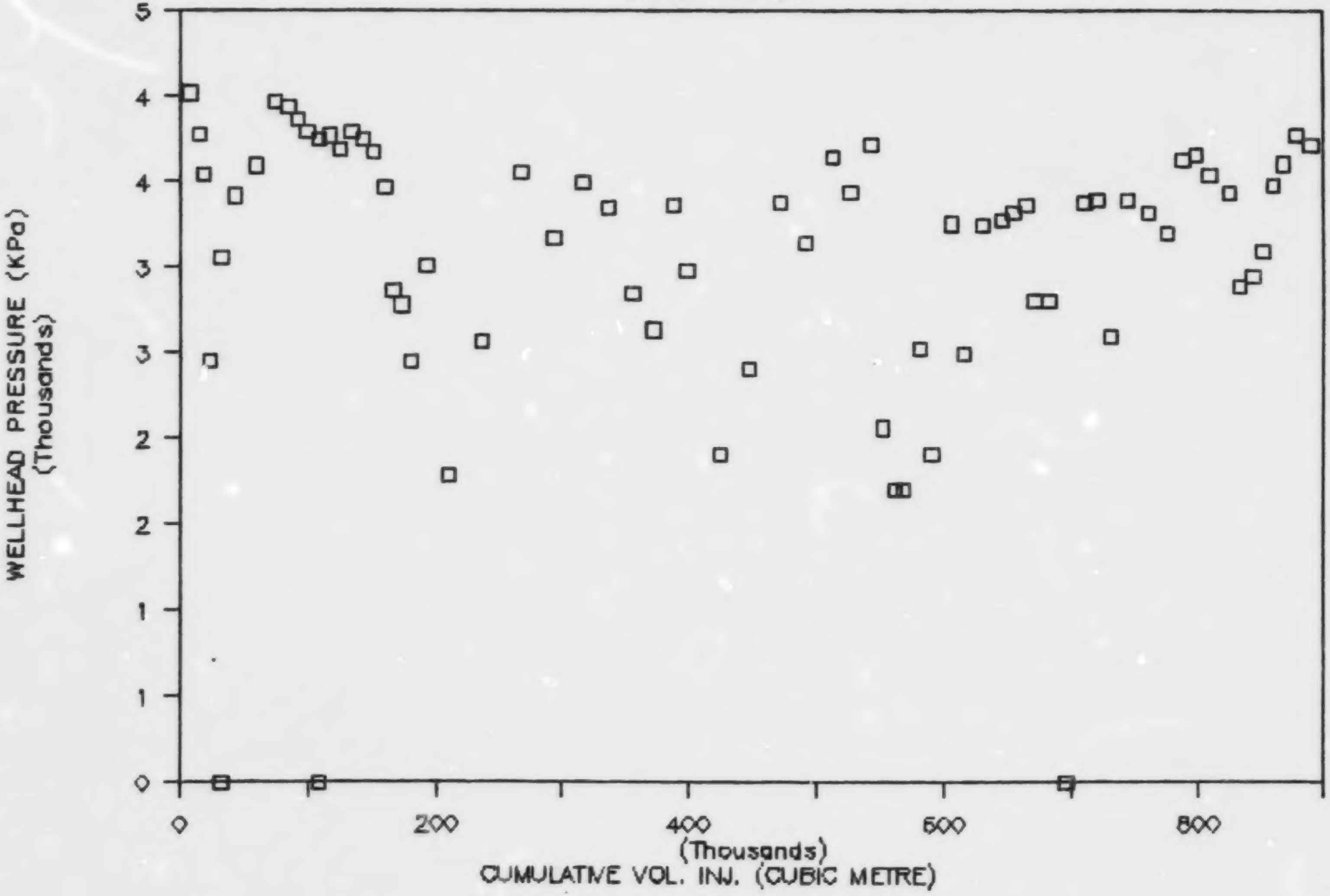
(1982–1987)



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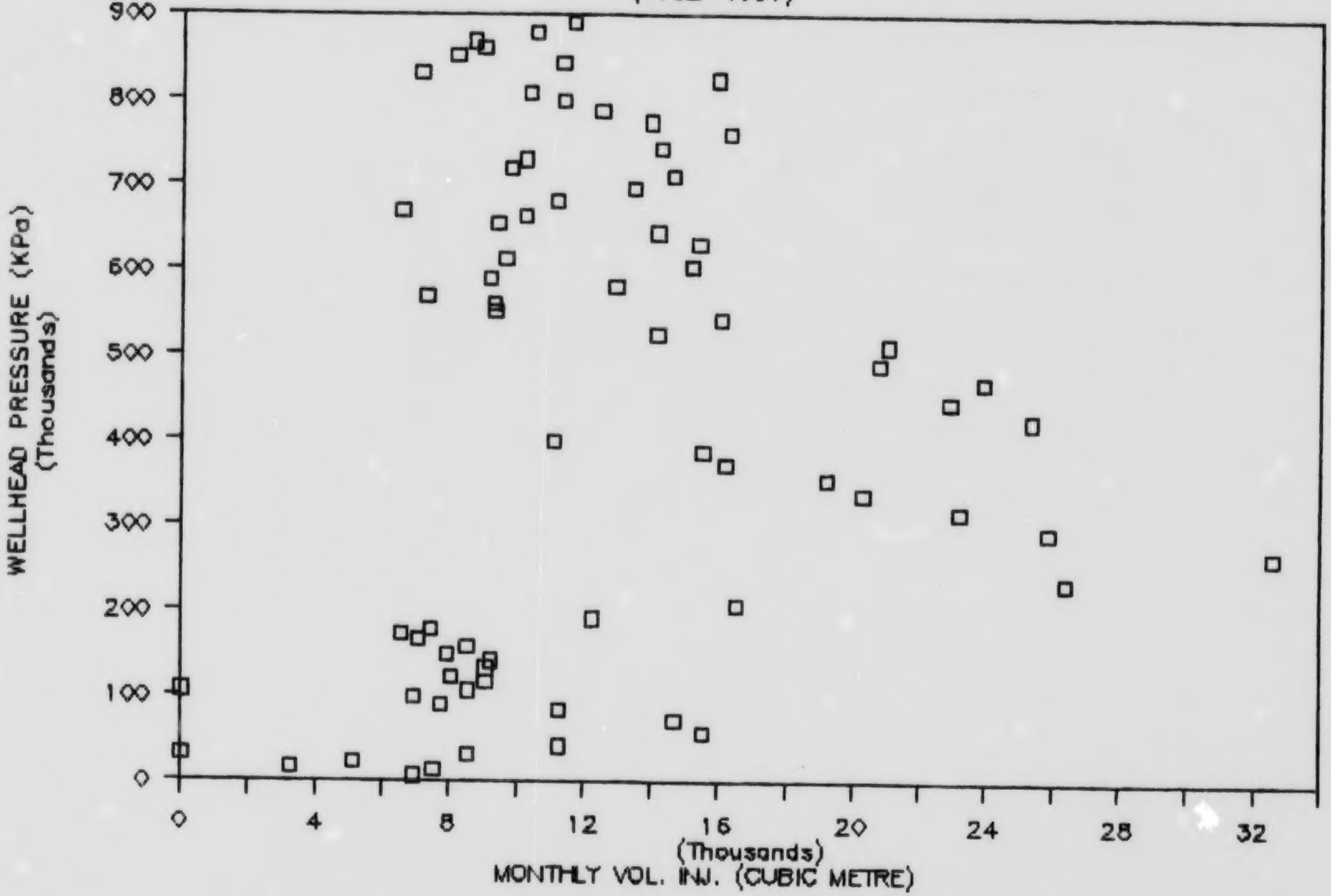
(1982–1987)



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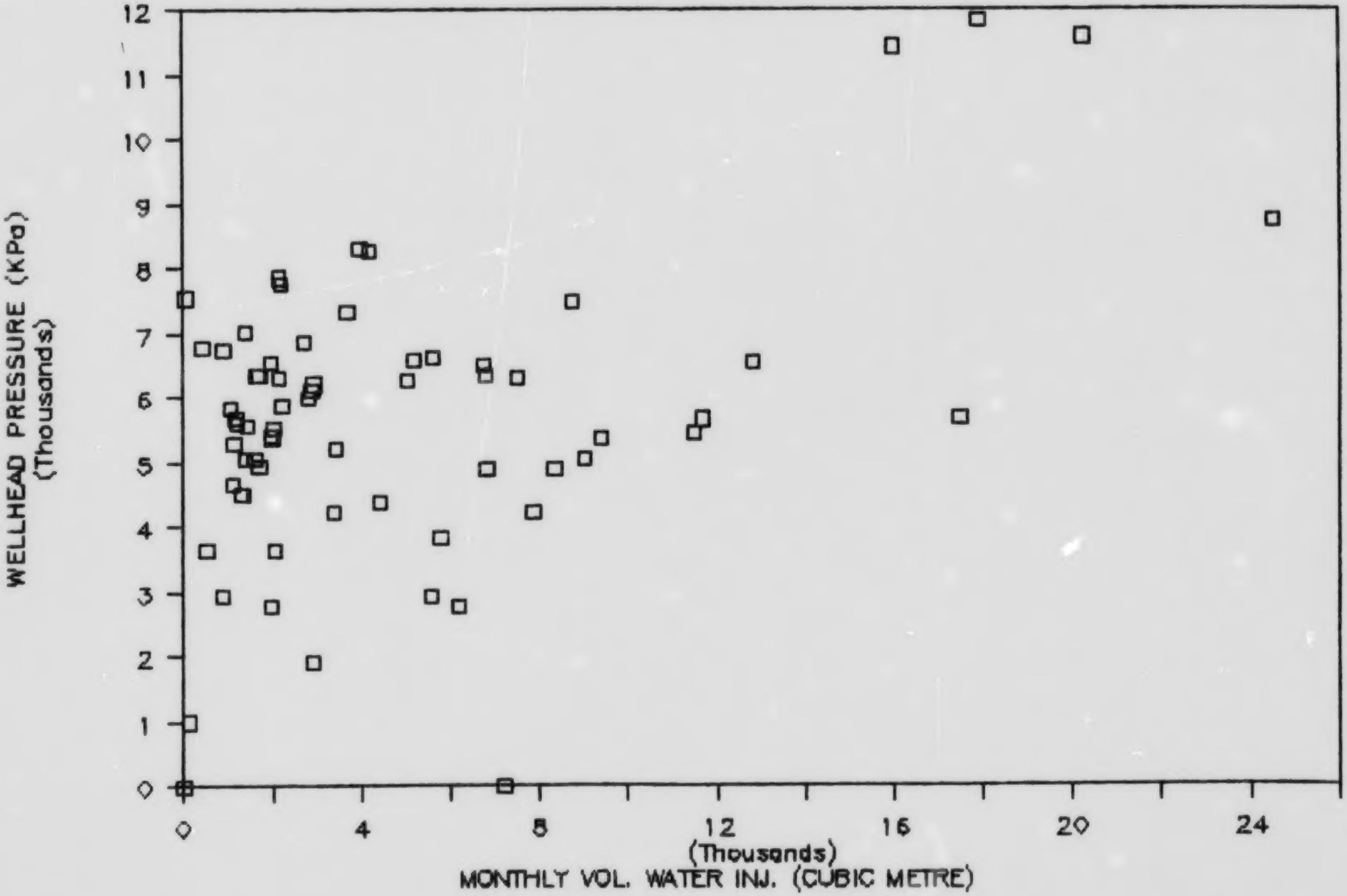

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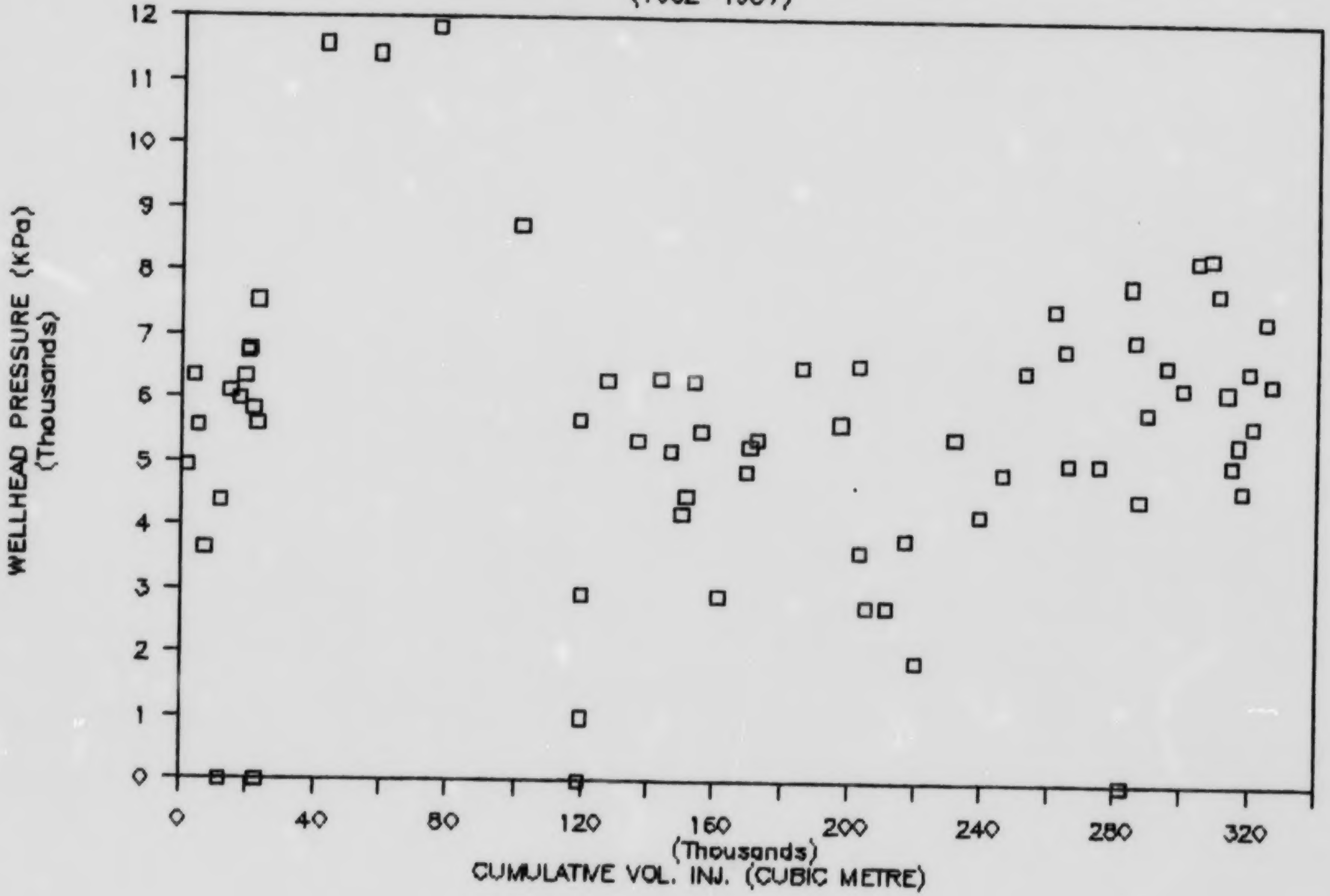
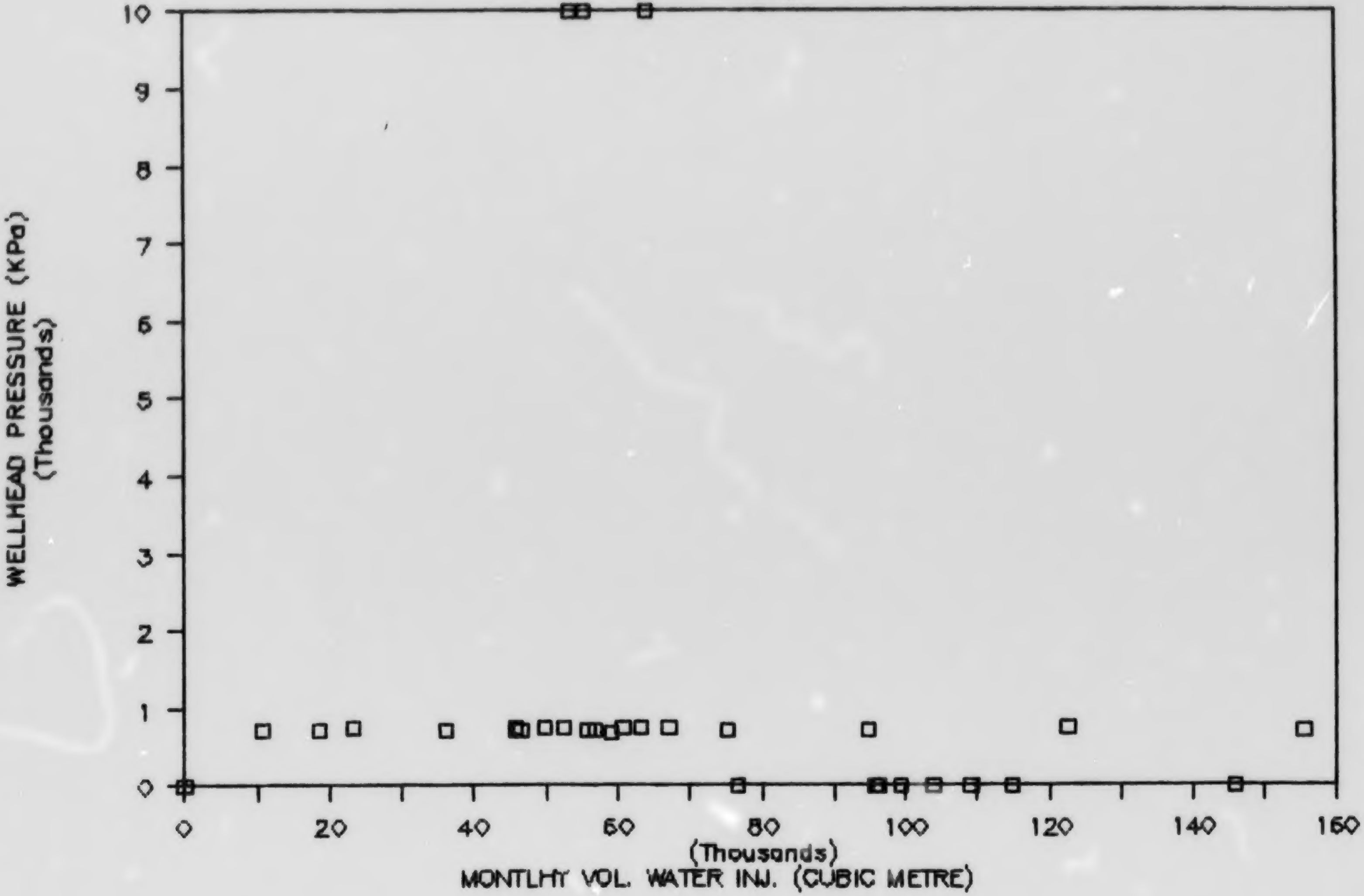
(1982–1987)



BP PCI MARGLK 10-8-66-5 W4M

(1985–1987)



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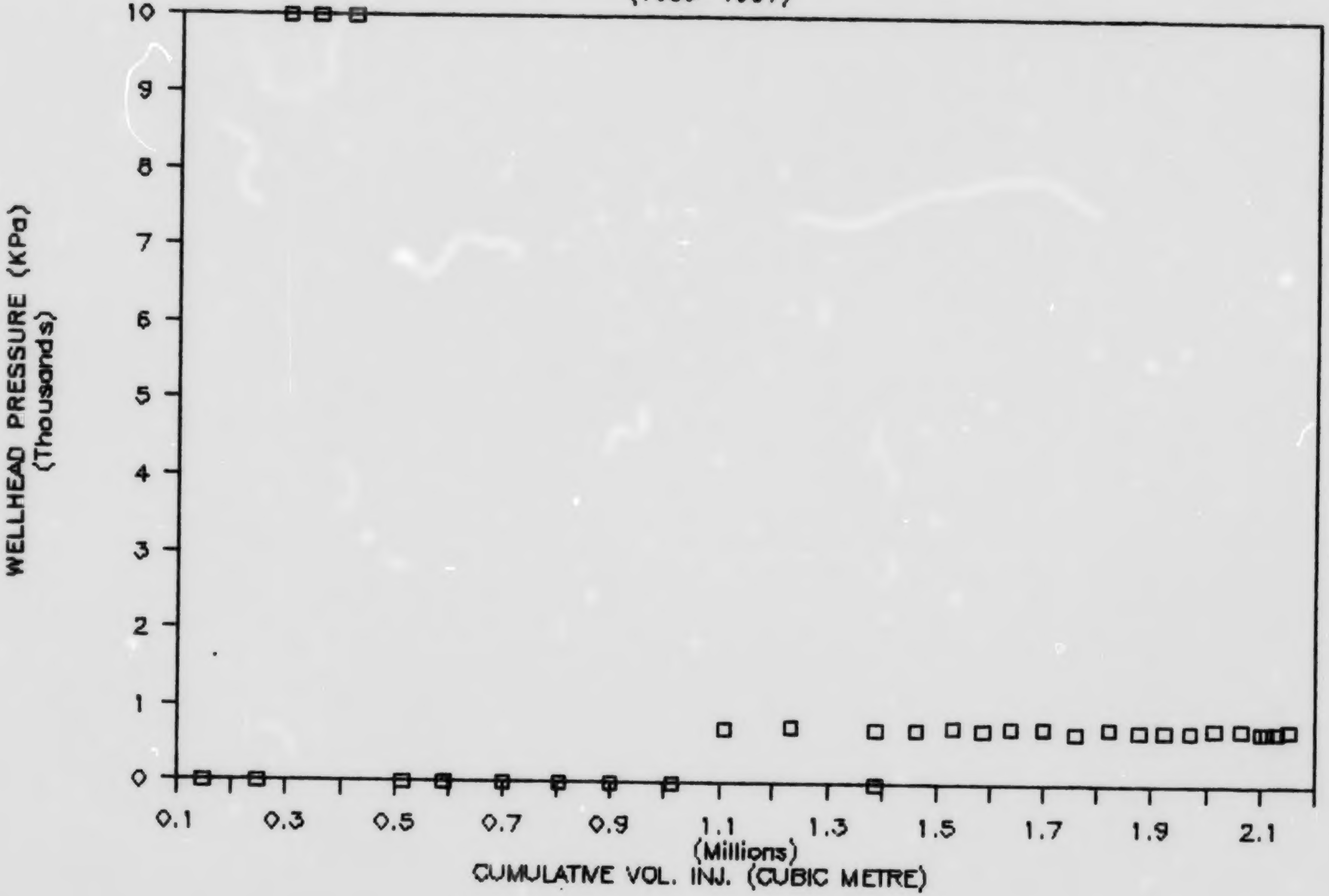
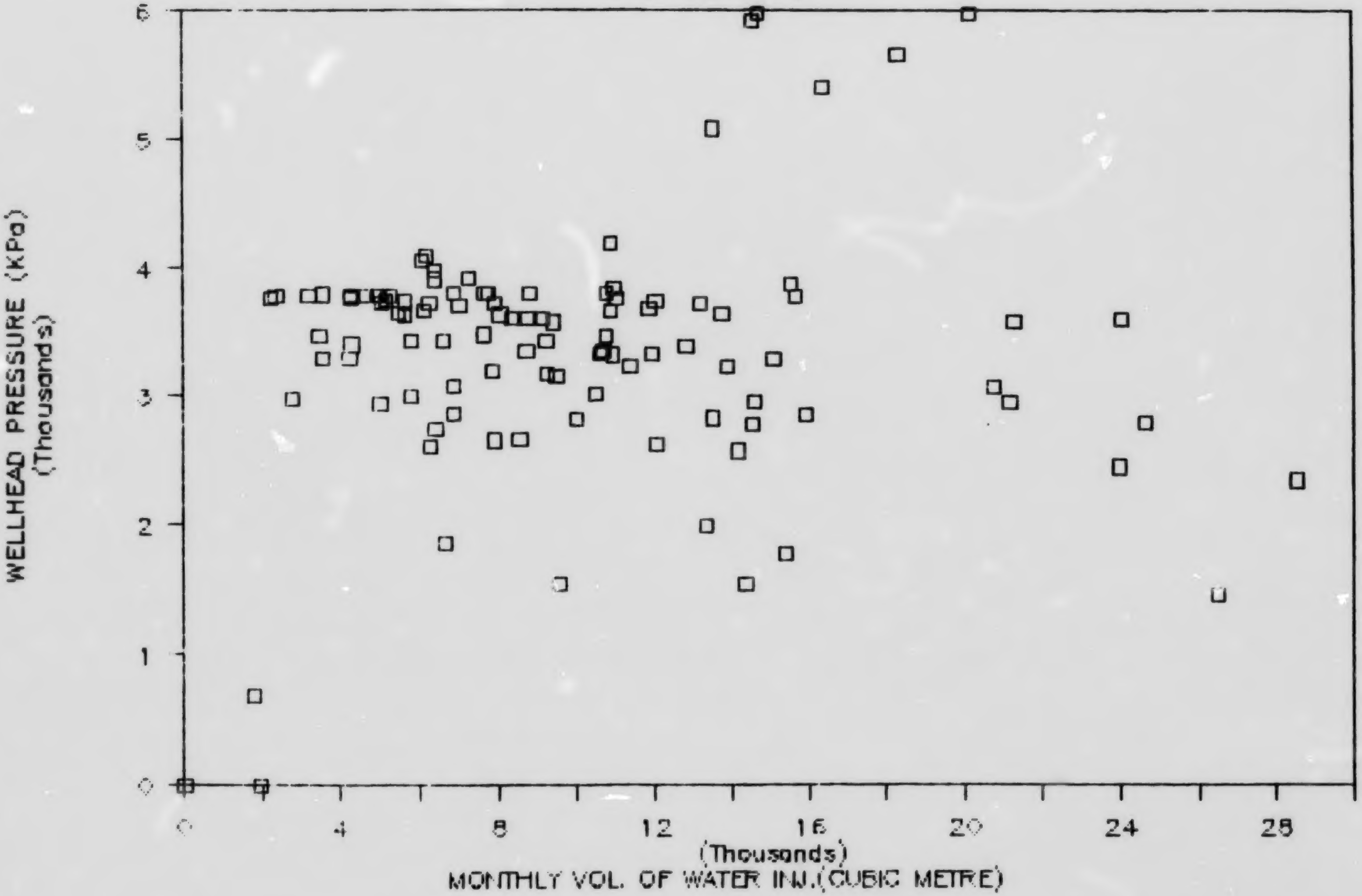
(1985–1987)



ESSO 78 INJ ETHELLK 4-17-65-3 W4M

(1979-1987)



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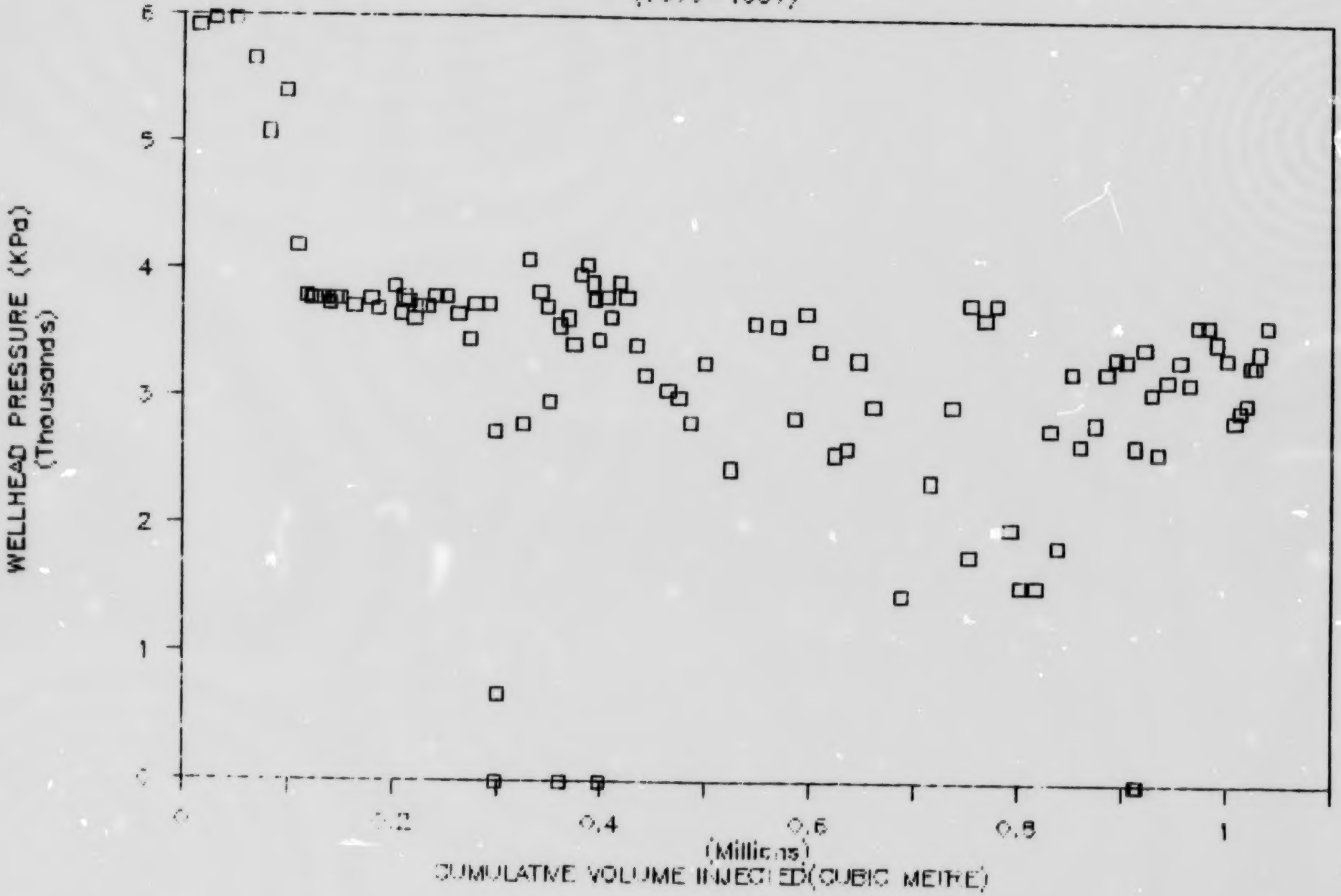
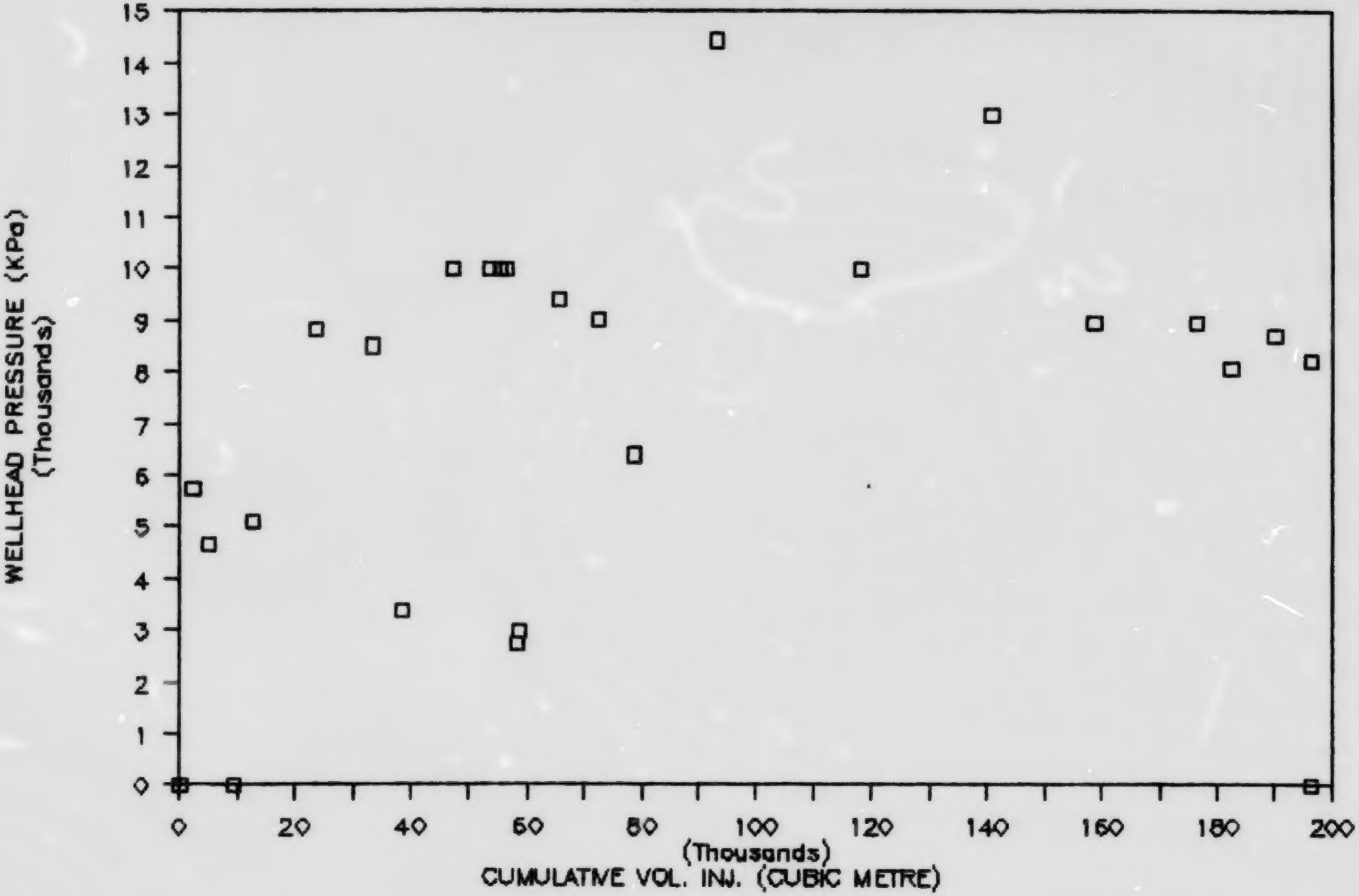
(1979–1987)



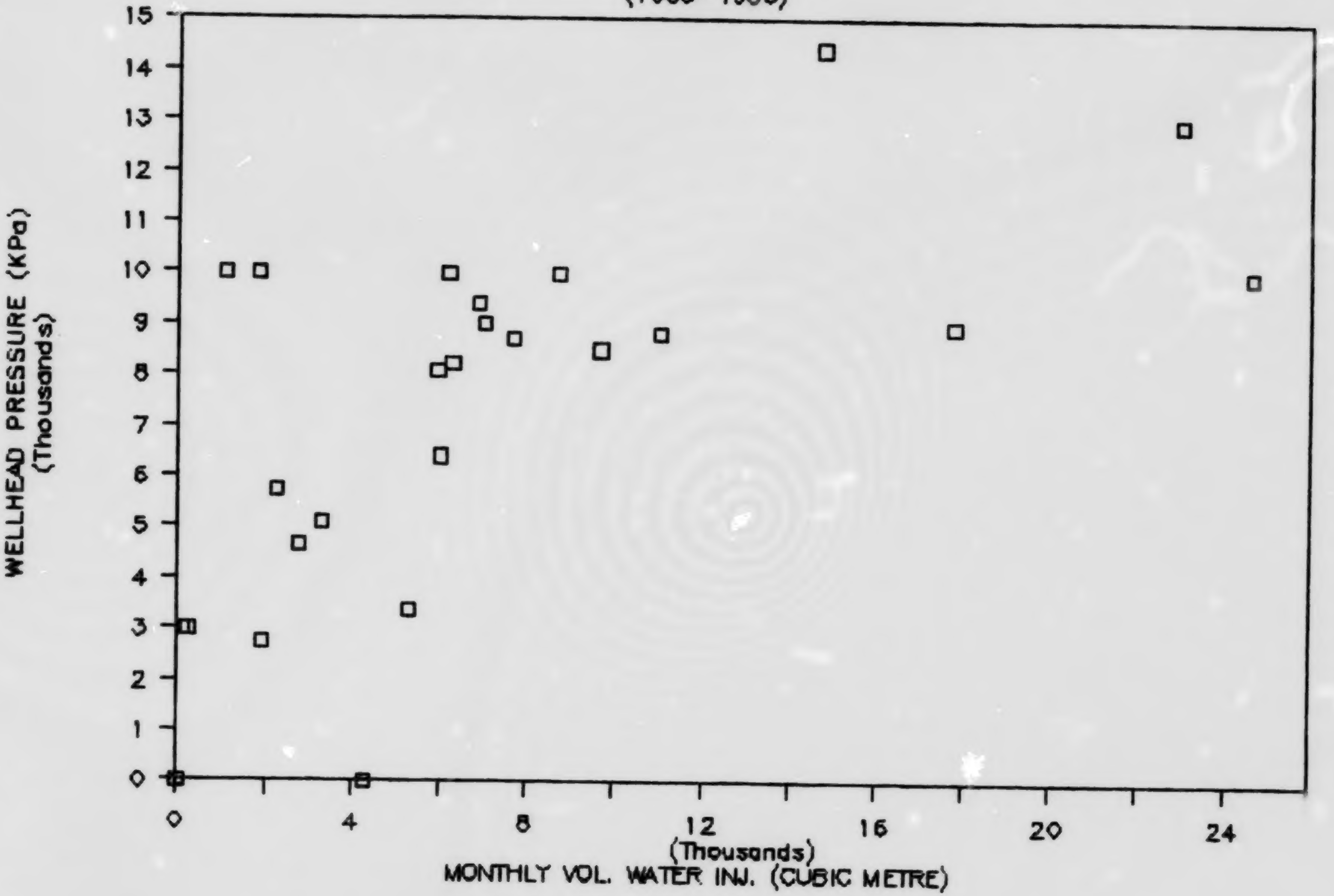
DOME AEC 10B4 MOORE 10-5-67-4 W4M

(1983-1986)



DOME AEC 10B4 MOORE 10-5-67-4 W4M

(1983–1986)



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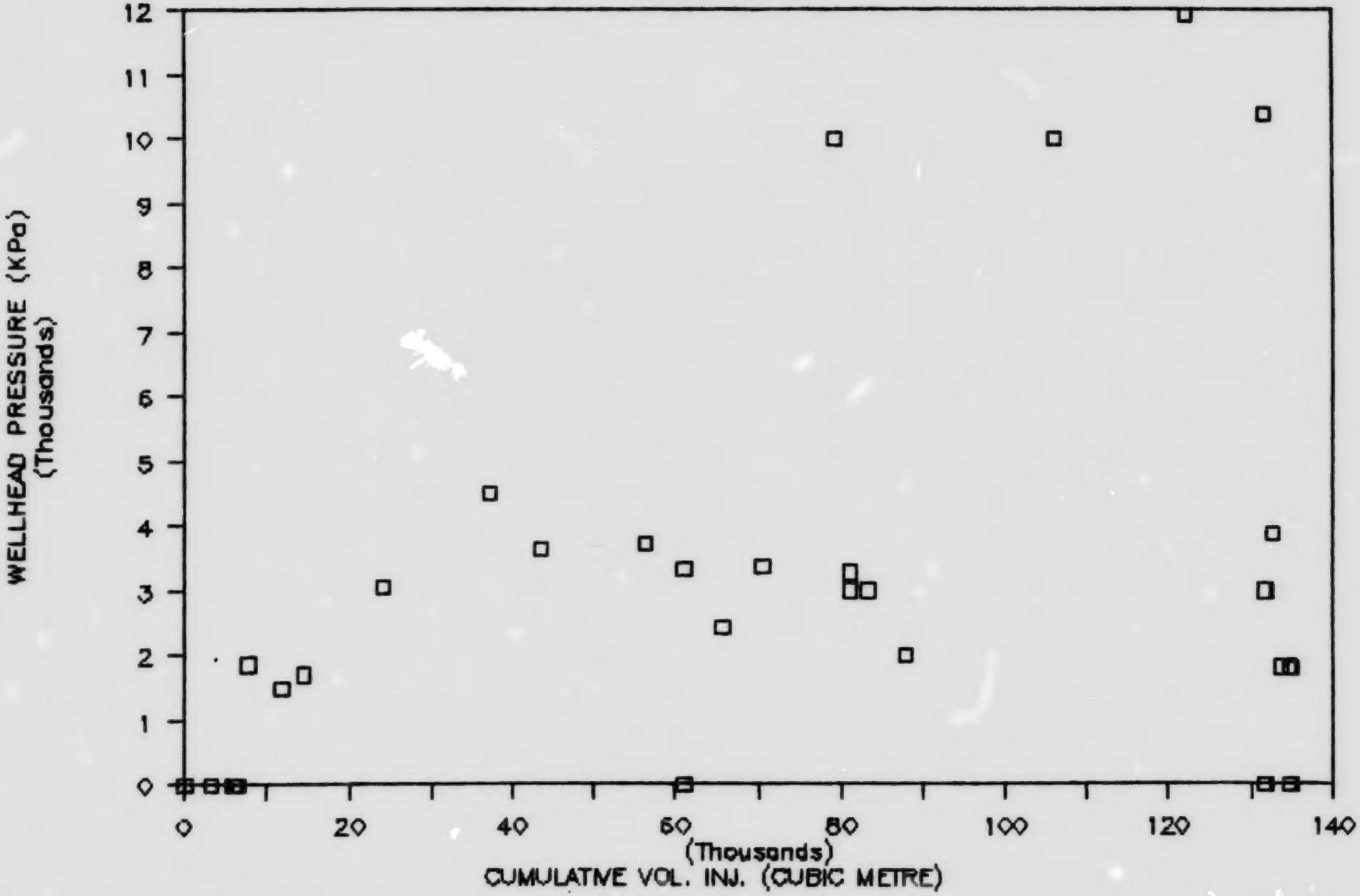
(1984–1986)



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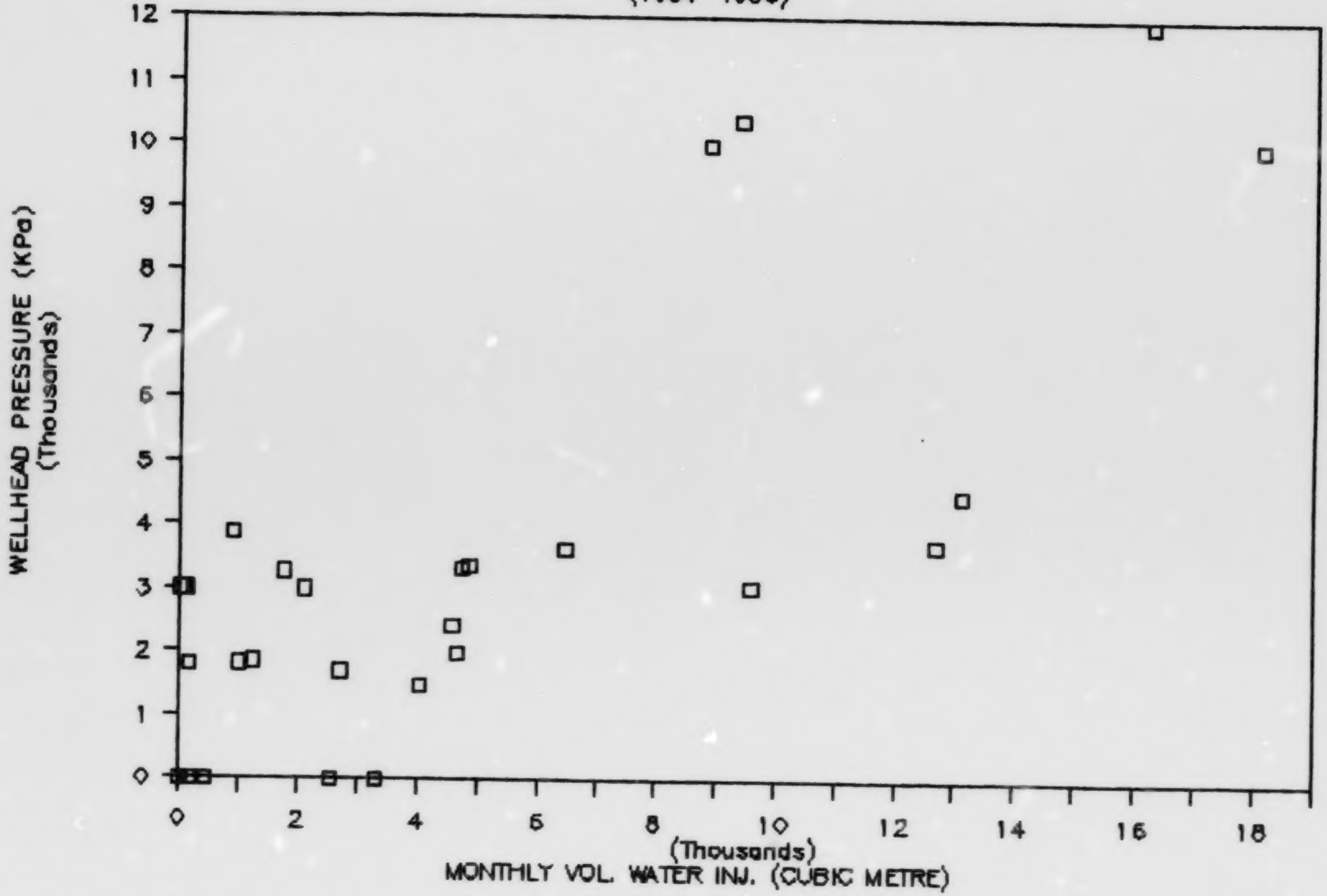
(1984–1986)



APPENDIX C

BASIN ANALYSIS GROUP
ALBERTA RESEARCH COUNCIL REPORT

Numerical Simulation of Deep Fluid Injection at the Swan Hills Facility of the Alberta Special Waste Management Corporation

Prepared for

Stanley Associates Engineering Ltd.

by

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Basin Analysis Group
Alberta Geological Survey
Alberta Research Council

Alberta Research Council
Edmonton, Alberta, Canada

1988-11-23

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EXECUTIVE SUMMARY

The Basin Analysis Group of the Alberta Geological Survey, Alberta Research Council, was asked to simulate numerically the variation during a specified 70 day period of bottomhole pressures at the deep injection well of the Alberta Special Waste Management Corporation at its Swan Hills facility. The initial bottomhole pressure at the beginning of the simulated period, and the injected volumes for each 3-day interval between April 22 and June 30, 1988, were supplied by Stanley Associates Engineering Ltd.

The deep hydrostratigraphy at the well site was delineated based on interpretation of geophysical logs. Six hydrostratigraphic units were identified in the Wabamun-Winterburn interval underlain and overlain by the thick tight shales of the Ireton and Exshaw aquitards, respectively. These units are, in ascending order: Lower Nisku aquitard, Upper Nisku aquifer, Calmar aquitard, Blue Ridge aquifer, Upper Winterburn aquifer and Wabamun aquifer. Deep well injection takes place in the Blue Ridge aquifer.

Values of permeability, porosity, hydraulic conductivity and specific storage were assigned to each hydrostratigraphic unit in this interval based on processing and synthesis of data from core analyses and drillstem tests (DST) run at the site. No precise value could be determined, but rather a range bounded by a lower limit (geometric average/median value of core data) and an upper limit (DST data). Two numerical simulations were performed, one with the lower and one with the upper limit of values for hydraulic parameters. The predicted bottomhole pressures are higher in the case for lower values of hydraulic parameters. The variation of

pressure values follows more closely the variation in the injection rates in the case of higher values of hydraulic parameters, because of higher aquifer diffusivity which allows a more rapid dissipation of the pressure wave induced by injection. A history match between computed and measured bottomhole pressures will allow a better estimation of the actual hydraulic parameters for the injection interval.

INTRODUCTION

The Basin Analysis Group of the Alberta Geological Survey, Alberta Research Council (ARC), previously studied the geochemical and hydromechanical effects of deep waste disposal at 27 sites in the Cold Lake area, Alberta, for a projected period of 30 years and injection rates of up to 31500 m^3/day at individual sites (Basin Analysis Group, 1987,1988). The resulting pressure buildups at the injection wells were compared with the fracturing thresholds of the rocks in the host aquifer, in order to assess the potential for initiation and propagation of vertical fractures. Unfortunately, a series of uncertainties and approximations are associated with most attempts to model and simulate flow in porous media, the most notable being the lack of information about the appropriate values of various parameters and variables used in simulations. These inherent aspects cast a degree of uncertainty over any results of numerical modelling.

The results of ARC studies were presented at a workshop held in September 1987 in Calgary with participation from industry and government agencies. At this workshop the need was identified to validate and calibrate through history matching the numerical model used by ARC. Based on the conclusion of the previous study that there is no interference between individual injection sites, it was suggested to find a plant operator in the Cold Lake area with accurate records of injected volumes and corresponding pressure variations in the host zone. The Department of Supply and Services awarded a contract on behalf of the National Hydrology Research Institute to Stanley Associates Engineering Ltd. (SAEL) to find and collect all the pertinent information for a site in the Cold Lake area, information to be used for validation of the ARC model. After a comprehensive search with the Energy Resources Conservation Board (ERCB) and individual operators in the region, SAEL concluded that no injection site in the Cold Lake area can be used for model validation because of the lack of reliable data regarding the volumes and pressure of injection (SAEL, 1988). Subsequently, SAEL was asked to check if the information needed for history matching is available at the Swan Hills facility of the Alberta Special Waste Management Corporation. A subsequent search identified a 70-day period between April and June 1988, for which records of bottomhole pressures and injected volumes are available. Consequently, Stanley Associates Engineering Ltd. supplied to ARC information about the initial bottomhole pressure and the three-day injection volumes for the entire 70-day period. Through a contract to SAEL, the Basin Analysis Group of the Alberta Geological Survey, Alberta Research Council, was asked to model and simulate deep well injection at the Swan Hills facility of the Alberta Special Waste Management Corporation. The results of this work form the content of this report.

The approach taken in the study was to delineate the hydrostratigraphy at the injection site based on the geophysical well logs, to select a proper interval for numerical simulations, to assign values to the hydraulic parameters needed in modelling, to set up a finite element grid for the selected interval, and to run simulations to predict the pressure buildup in the host formation at the well. Two simulations were run, according to the terms of the contract with SAEL. Stanley Associates Engineering Ltd. will compare the results of numerical simulations with the actual bottomhole pressures recorded during the respective 70-day period.

SITE HYDROSTRATIGRAPHY

The waste disposal facility of the Alberta Special Waste Management Corporation is located near the town of Swan Hills in west-central Alberta. A deep injection well (CSL Ethel 13-6-67-8-W5M) was drilled in 1986 at the site, reaching the top of the Ireton Fm. (Woodbend Group). Selected geophysical well logs of the well are presented in figure 1, together with the location of drillstem tests and cores, and generalized stratigraphy.

A lithologic breakdown of the strata at the injection site is based on the examination of geophysical logs; no core was examined for lithological and stratigraphic delineation. The well log interpretation was conducted from the first reliable interval, below Tertiary and Quaternary strata, from a drill depth of 351 m (elevation 740 m) to the total depth at 2046 m (elevation -955 m). The lithology is described here as either sand/shale or carbonate/shale mixtures with an estimate of shale content (table 1). The lithologic subdivision from geophysical logs was grouped into hydrostratigraphic units (table 1), based on generally known hydraulic characteristics of sandstones, shales and carbonates. The hydrostratigraphic delineation is consistent with the regional systems of aquifers and aquitards (Basin Analysis Group, 1985), and is supported by the values of hydraulic parameters determined from drillstem tests and core analyses to be presented later.

Table 1: Stratigraphic, lithologic and hydrostratigraphic delineation of the sedimentary column at the injection well CSL ETHEL 13-6 (13-6-67-8W5 KB=1091 m) at the Swan Hills Waste Disposal Facility.

PERIOD	STRATIGRAPHIC TOP	DD	ELEVATION	LITHOLOGY	% SHALE	HYDROSTRATIGRAPHIC UNIT
	GROUND SURFACE	0	1086	na	na	na
		351	740	SAND/SHALE	40	
	BELLY RIVER	413	678	SAND/SHALE	30	AQUIFER
		682	409	SAND/SHALE	20	
	LEA PARK	780	311	SHALE/SAND	50	
C	COLORADO SHALE	830	261	SHALE/SAND	70	AQUITARD
R		863	228	SAND/SHALE	45	
E	BAD HEART	883	208	SAND/SHALE	30	AQUIFER
T	MUSKIKI	887	204	SHALE/SAND	50	
A	2WS	988	103	SHALE/SAND	65	
C		1035	56	SHALE	80	AQUITARD
E		1045	46	SHALE/SAND	55	
O		1133	- 42	SHALE/SAND	65	
U	BFS	1152	- 61	SHALE/SAND	55	
S	VIKING	1205	-114	SAND/SHALE	45	
	JOLI FOU	1213	-122	SHALE/SAND	70	
	MANNVILLE	1228	-137	SAND/SHALE	30	
		1380	-289	SAND/SHALE	40	AQUIFER
	GETHING	1402	-311	SAND/SHALE	30	
		1487	-396	SAND	0	
	BANFF	1505	-414	CARB/SHALE	10	
M		1527	-436	CARB/SHALE	30	
I		1585	-494	SHALE/CARB	70	AQUITARD
S		1605	-514	CARB	0	AQUIFER
S		1617	-526	CARB/SHALE	25	
	EXSHAW	1638	-547	SHALE	100	
		1640	-549	CARB	20	AQUITARD
		1645	-554	SHALE	100	
	WABAMUN	1651	-560	CARB	0	
D	GRAMINIA	1896	-805	CARB	10	AQUIFER
E	BLUE RIDGE	1905*	-814	CARB	5	
V		1925*	-834	CARB	10	
O	CALMAR	1950	-859	CARB/SHALE	50	WEAK AQUITARD
N	NISKU	1968	-877	CARB	10	
I		1975	-884	CARB	0	AQUIFER
A		1983	-892	CARB	10	
N		2005	-914	CARB/SHALE	35	WEAK AQUITARD
	IRETON	2030	-939	SHALE	na	AQUITARD

* injection interval
na not available

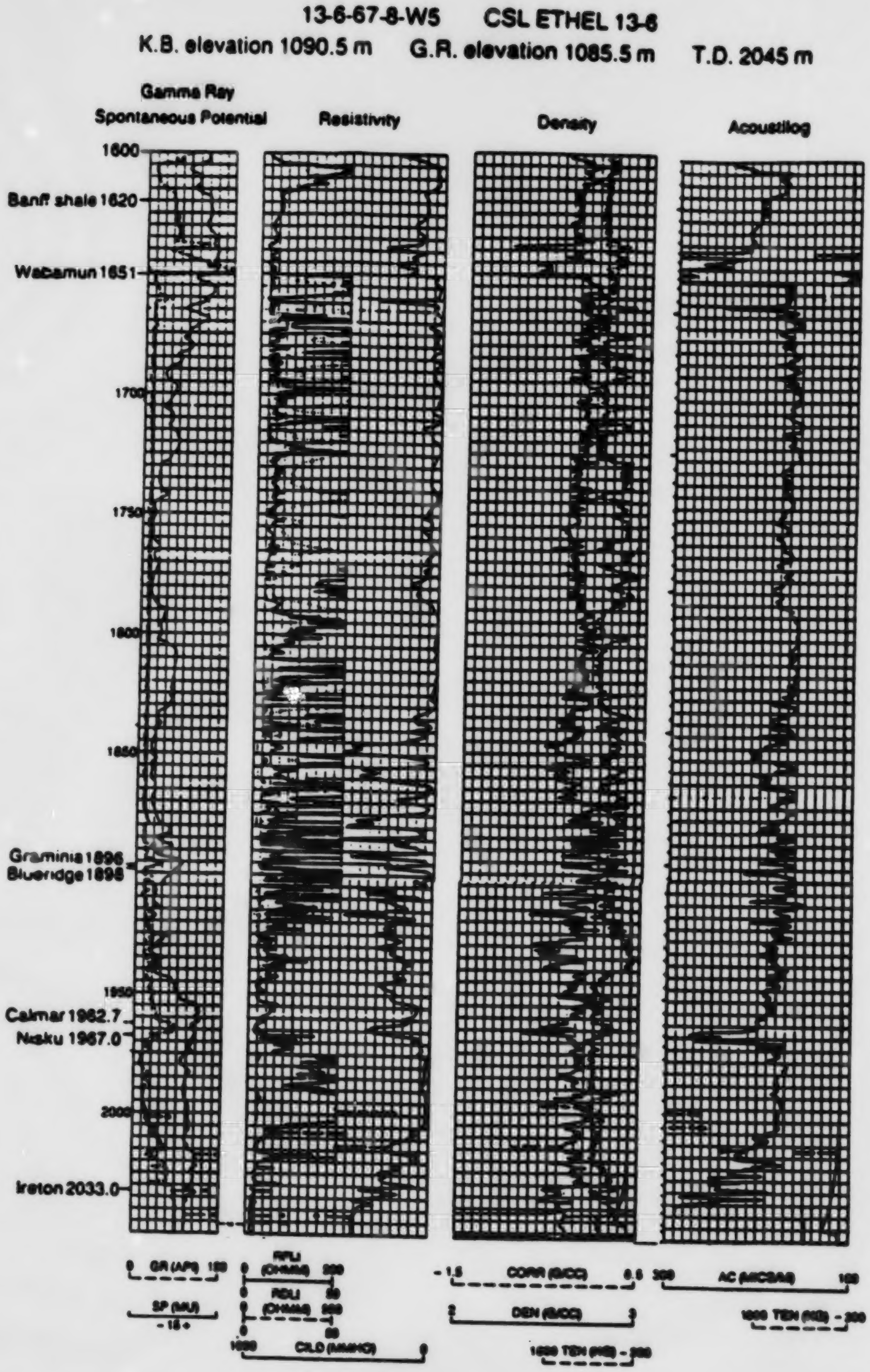

Figure 1: Geophysical well logs at CSL Ethel 13- 6-67-8-W5.

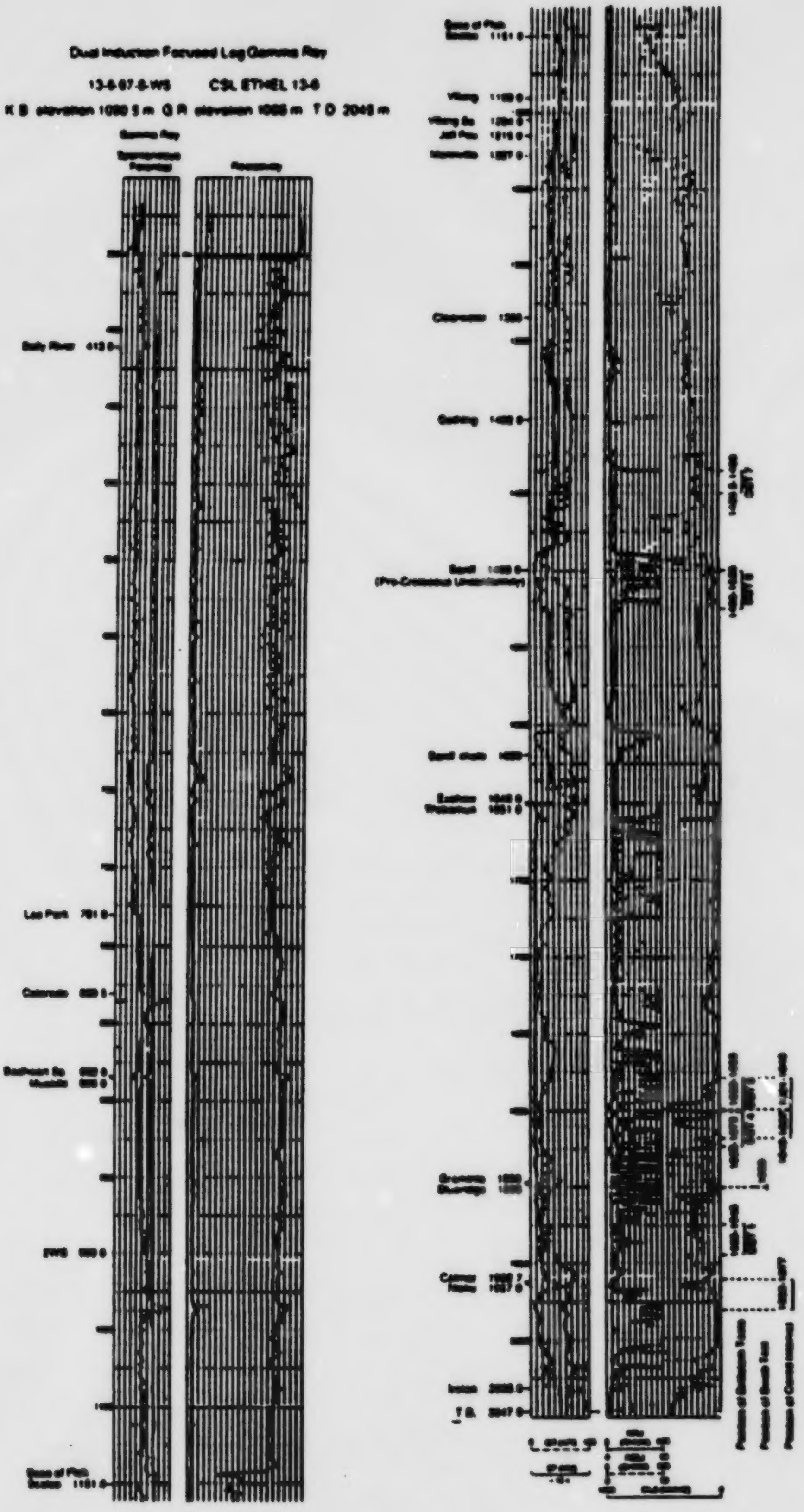

Figure 1: Continued

The Devonian portion of the stratigraphic column, between the base of the log and middle of Exshaw Fm., consists of carbonates and marine shales. The Ireton Formation is picked at -939 m, which is very close to the base of the interpretable portion of the logs. Since very little of the Ireton Formation is logged, it is difficult to establish the shale content. However, based on the previous regional study (Basin Analysis Group, 1985), it is assumed to be a tight aquitard, with a permeability approaching values characteristic of an aquiclude. The Nisku Formation, picked at -877 m, consists of carbonates with shaley stringers. In the upper 37 m the shale content is about 10% of the unit, while in the lower 25 m the Nisku Formation appears to be considerably more dirty, with up to 35% shale content. For this reason, the upper and lower parts of the Nisku Fm. are considered to be an aquifer and a weak aquitard, respectively. The Calmar Formation is a shaley carbonate with thin interbeds of shales and carbonates each making up 50% of the unit. The shale content tends to increase towards the base of the unit, with a shale rich zone in the lower 6 m. The ERCB pick locates the top of Calmar Fm. at -871 m, which coincides with the shale rich zone at the base of the interval as described previously. The top of Calmar Fm. was picked at a significantly higher elevation than that of the ERCB based on the density and caliper log response indicating an increase of the shale content starting at -859 m. The Calmar Fm. is considered to be an aquitard. The upper portions of the Winterburn Group are dominantly clean carbonates of the Blue Ridge Formation (-814 m) and the Graminia Formation (-805 m) with less than 10% of the interval being shale. The overlying Wabamun Group, picked at -560 m, is a clean carbonate with virtually no shale content, which gives a distinctive response on the gamma ray log. The rocks between the top of Wabamun Group and the top of Calmar Formation form the Wabamun-Winterburn aquifer system. The Exshaw Formation is picked at -547 m and is a very pure shale, with the exception of a thin carbonate horizon near the top. The Banff Formation, which marks the top of the Mississippian, is picked at -414 m, and is dominantly a shale unit (70% shale) with several thin carbonate horizons locally making up to 90% of a particular interval. The Exshaw and Banff formations form a tight aquitard overlying the Wabamun-Winterburn aquifer system.

The Cretaceous portion of the stratigraphic column consists of shale-dominated clastics. The Gething Formation, picked at -311 m, has a shale content of approximately 30%; however, towards the base of the unit there is a strong gamma ray response at -396 m which is indicative of a very clean sandstone. The Mannville Group (picked at -137 m) is dominantly sandy, having a shale content ranging from 30% to 40%. The overlying Joli Fou Fm., picked at -122 m, is a shale-dominated unit with less than 30% sand content. The Viking Sandstone, picked at -114 m, is a 8 m thick sandy unit with less than 45% shale content. The Base of Fish Scales (-61 m), Second White Speckled Shale (103 m) and Muskiki (204 m) formations are dominantly shaley, averaging 65% shale, with locally rich zones containing more than 80% shale. The Bad Heart Formation, picked at 208 m, shows a strong gamma ray response indicating a fairly clean sandstone with approximately 30% shale content. The overlying Colorado Shale, picked at 261 m, has less than 30% sand, with the shale content increasing towards the top. The Lea Park Formation, picked at 311 m, is not as pure as the underlying Colorado Shale, as it only contains slightly more than 50% shale. Finally, the Belly River Formation, picked at 678 m, marks an Upper Cretaceous sand-dominated unit with shale content increasing upwards from 20% to 30%. Clastics of the Tertiary and Quaternary portion of the stratigraphic column overlie the Belly River Formation. The hydrostratigraphic delineation of the Cretaceous strata is presented in table 1.

The injection of liquid waste takes place in the Blue Ridge Fm. of the Winterburn Group, Upper Devonian, in several perforated intervals at 1912.5-1917.5, 1919-1923, 1924-1925, 1933-1934 and 1938-1944 metres depth. The previous regional evaluation for deep waste disposal at the Swan Hills facility of the Alberta Special Waste Management Corporation (Basin Analysis Group, 1985), has shown that continuous injection of 225 m^3/day over a very long period of time in the lower part of the Winterburn Group will not affect strata below the Ireton Fm. or above the Banff Fm., due to the very strong confining characteristics of the underlying and overlying Ireton and Exshaw-Banff aquitards, respectively. The actual rate of injection varied between 66 and 550 m^3/day during the 70-day period to be simulated. Considering also the short injection time interval and the considerable thickness of the Wabamun-Winterburn aquifer system (almost 300 m), it is expected that no effects of injection have been felt outside of the two major confining aquitards. Therefore, only the interval between the top of Ireton Fm. and the top of the Wabamun Group was considered for numerical simulations, to be presented in the following chapters.

HYDRAULIC CHARACTERISTICS

The injection of fluids in a deep aquifer can be modelled using the following partial differential equation (Bear, 1972):

$$\mathrm{div}\,[\overset{=}{K}\ \mathrm{grad}\ (H)] + Q = Ss\,\frac{\partial H}{\partial t} \qquad (1)$$

where $\overset{=}{K}$ is the hydraulic conductivity tensor, H is hydraulic head, Q represents sources, Ss is specific storage and t is time. In order to solve equation (1) there is need to define the geometry of the aquifers and aquitards in the system being modelled, and to assign characteristic, or representative, values to the hydraulic parameters $\overset{=}{K}$ and Ss. The hydraulic conductivity and the specific storage can be computed according to:

$$K = -\frac{k\rho g}{\mu}; \qquad Ss = \rho g[(1-n)\alpha + n\beta] \qquad (2)$$

where k is intrinsic permeability, ρ is density, g is the gravitational constant, μ is dynamic viscosity, n is porosity, and α and β are the rock and fluid compressibility, respectively.

As described in the previous chapter, the system between the Ireton and Exshaw-Banff aquicludes is comprised, in ascending order, of Lower Nisku aquitard, Upper Nisku aquifer, Calmar aquitard, Upper Winterburn aquifer and Wabamun aquifer. Three cores were taken in the injection well from the Wabamun-Winterburn interval. There are 93 core analyses from the Wabamun Group, 2 from the Calmar Fm. and 5 from the Nisku Fm. In addition, three successful drillstem tests were run at the injection site, one in the Blue Ridge Fm. and two in the Wabamun Group. In order to improve, if possible, the assessment of the characteristic values for the hydraulic parameters used in modelling, the Alberta Geological Survey Well Data Base was searched for additional drillstem tests and core analyses within the Wabamun-Winterburn interval, and within a two township radius from the injection site. Only one drillstem test in the upper part of Nisku Fm. was found at 10-30-67-10W5M. Two wells, at 7-29-65-7W5M and 13-6-65-8W5M, contain core analyses, again in the upper Nisku Fm. The location around the injection site of wells with drillstem tests or core analyses in the Wabamun-Winterburn interval is shown in figure 2.

The basic information contained in core analyses refers to the length of the analyzed interval, maximum horizontal permeability k_{max}, the value of horizontal permeability at 90 degrees with the direction of the maximum permeability, k_{90}, the vertical permeability k_v, and porosity n. Permeability values less than $10^{-17} m^2$ could not be measured due to limitations of laboratory devices. Therefore, there are a number of determinations which indicate this value of permeability. For each component of the permeability tensor, k_{max}, k_{90} and k_v, and for each well and interval, the core data were processed in terms of the following characteristic values: minimum, harmonic average, geometric average, median value, weighted average, arithmetic average, and maximum. The porosity data were processed in the same way. The results of the data processing are presented in the appendix (tables A1-A4). The median values were obtained from frequency plots of permeability (logarithmic scale) and porosity, presented also in the appendix (figures A1-A12).

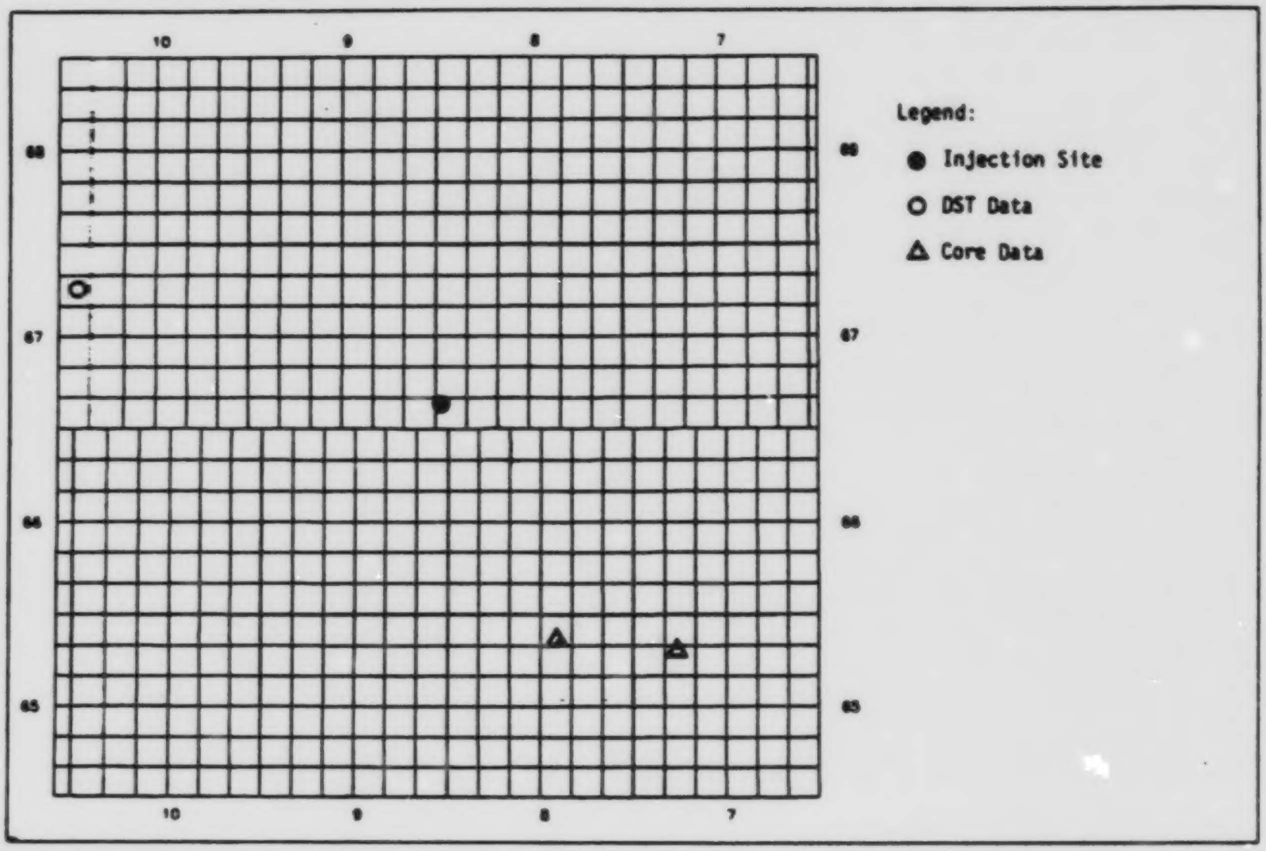
10
9
8
7
68
67
66
65
Legend:
● Injection Site
○ DST Data
△ Core Data

Figure 2: Distribution of wells with drillstem test and core analyses in the Wabamun-Winterburn interval within a two townships distance from the injection site.

The representative value for distributed earth properties is usually the geometric average (Matheron, 1967), which coincides with the median value in the case of a sufficiently large data sample from a statistically homogeneous population. It can be seen from tables A1-A4 that indeed the median value and the geometric average are relatively close. The geometric average is representative particularly when the samples are distributed along the direction of the fluid flow. For samples distributed normal to flow direction, as in the case of a vertical core, it can be argued that the majority of flow will take place through the region of minimum resistance, i.e. maximum permeability. For this reason, the average weighted by sample length of the core analyses can be considered also as being representative. In reality, the fluid flow is neither parallel nor normal to the cored intervals, particularly in the case of pumping or injection. Therefore, the true representative permeability value is found somewhere between the geometric and weighted averages. The results of core data processing confirm the hydrostratigraphic delineation at the injection site, namely that the Lower Nisku Fm. and the Calmar Fm. are aquitards, and that the Wabamun Group is an aquifer.

Interpreted information from the three drillstem tests run at the injection site was acquired from the Canadian Institute of Formation Evaluation Ltd. (CIFE), namely the formation pressure, the slope of the Horner plot, the temperature and salinity of formation waters, and the amount of recovered fluid. Further interpretation by the ARC provided values of bulk permeability for the Blue Ridge Fm. ($k = 5.6 \times 10^{-14} m^2$) and for the Wabamun Group ($k = 4.3 \times 10^{-14} m^2$). As expected and already noted in the literature, the values of bulk permeability as determined from drillstem tests are greater by about one order of magnitude than the values of overall permeability obtained from core analyses. Generally it is thought that this is a scale effect, and that drillstem tests are more representative than cores because they involve a much larger mass of rock than a core plug. The drillstem tests results confirmed the initial assumption that the Blue Ridge Fm. and Wabamun Group are aquifers.

The hydraulic heads in the Blue Ridge Fm. and in the Wabamun Group at the time of well drilling were computed based on formation pressure. The three values range between $H = 392$ m and $H = 416$ m, with an average of $H = 405$ m. Given the fact that there are a series of errors and approximations in the measurements and interpretation of drillstem tests, it is considered that basically the hydraulic head is the same in the entire interval between the top of the Calmar Fm. and the top of the Wabamun Group, showing hydraulic continuity.

Median values of porosity were used to compute the specific storage Ss. The water compressibility is $4.7 \times 10^{-8} Pa^{-1}$, but no actual values of rock compressibility are available. Literature values were used (Birch, 1966), leading to values of the specific storage between $1.2 \times 10^{-4} m^{-1}$ and $2.6 \times 10^{-4} m^{-1}$. These values compare well with the regional values determined previously (Basin Analysis Group, 1985).

NUMERICAL SIMULATIONS

The finite elements model FE3DGW (Gupta et al, 1984a, 1984b) was used to simulate the deep waste injection over the 70-day period at the Swan Hills facility of the Alberta Special Waste Management Corporation. Previous simulations of injecting up to 31500 m^3/day over 30 years in thinner aquifers in the Cold Lake area have shown that the effects of injection will be limited to a close area within a 1 km radius from the respective well (Basin Analysis Group, 1987, 1988). Based on these results, the model area was restricted to four sections around the injection site, namely Sections 6 and 7, Twp. 67, Rge. 8, W5M, and Sections 1 and 12, Twp. 67, Rge. 9, W5M. A quasi-radial areal finite element grid was set up, grid centered at the injection well and composed of 432 surface nodes defining 416 surface elements (figure 3).

Given the quasi-radial nature of the problem being simulated, the grid spacing is very small close to the injection site, becoming larger as the distance from the well increases. It should be kept in mind that each node in the grid represents, in fact, an area around that node, an area defined by a radius of equivalence r_e. In finite difference modelling, the value of the radius of equivalence r_e depends on the grid spacing Δx and Δy according to the relation (Beljin, 1987):

$$r_e = 0.14((\Delta x)^2 + (\Delta y)^2)^{1/2} \qquad (3).$$

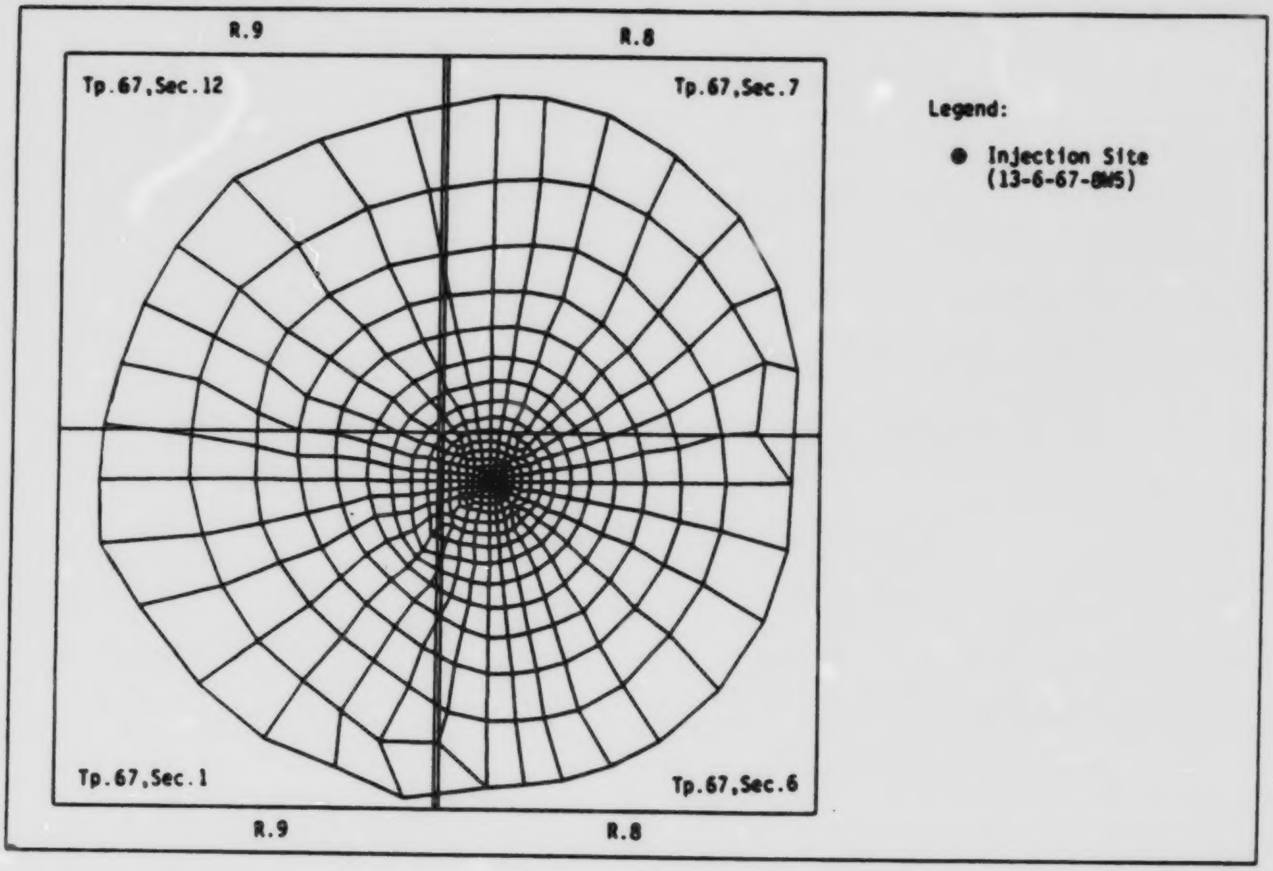
R.9
R.8
Tp.67,Sec.12
Tp.67,Sec.7
Legend:
● Injection Site
(13-6-67-8W5)
Tp.67,Sec.1
Tp.67,Sec.6
R.9
R.8

Figure 3: Plan view of the finite element grid used for simulating deep well injection at the Swan Hills Waste Disposal Facility.

There is no similar relationship for finite element modelling, but the grid was designed to be basically rectangular around the injection well, such that relation (3) could be used to estimate the radius of equivalence of the node representing the injection well. Using relation (3), the radius of equivalence of the injection node is estimated to be approximately 3.6 m. This means that the pressure variations obtained at the injection node as a result of the numerical simulations represent in reality the pressures that would be measured at this distance from the injection well.

Six layers were considered in the hydrostratigraphic sequence to be modelled. They are, in ascending order: Lower Nisku aquitard, Upper Nisku aquifer, Calmar aquitard, Blue Ridge aquifer (up to the injection level), Upper Winterburn aquifer, and Wabamun aquifer. Although injection takes place at several levels between 1912.5 and 1944 m depth, no information is available about how the injected volumes were distributed among the various perforated intervals. Also, the depth (or elevation) of the pressure-measuring device is not indicated. Therefore, it was considered that the injection took place at a single point located at 1927 m depth (-829 m elevation at 23 m above the top of the Calmar aquitard), taken also as the top of the Blue Ridge aquifer. The interfaces between the various layers were automatically built taking into account the local dip direction of 240° and dip of 9.1 m/km of Upper Devonian strata. The three-dimensional finite elements were automatically constructed from the surface elements along verticals from the surface nodes to the points of intersection between these verticals and the hydrostratigraphic interfaces. Correspondingly, the total number of nodes and elements in the system is 3024 and 2874 respectively.

It was considered that the boundary conditions along the edge of the area being modelled are defined by the initial formation pressure (hydraulic head H = 405 m) obtained from the drillstem tests run at the time of well drilling. The initial pressure at the injection node at the beginning of the 70-day time period was 15,359 kPa, corresponding to a hydraulic head H = 737 m. The difference between the bottomhole pressure at the injection site and the initial formation pressure is attributable to the injection operations prior to the 70-day period to be simulated.

As discussed in the previous chapter, there is a degree of uncertainty about the true values of hydraulic conductivity K and specific storage Ss characteristic, or representative for the area being modelled. The only information available for the aquitards is provided by the core analyses, with values in a narrow range. For the aquifers, the problem is more difficult, because the range of variation for permeability values spans several orders of magnitude. However, the geometric average/median value should be considered the lowermost limit of the representative value, while the value obtained from drillstem tests should be considered as the uppermost limit. Examination of equation 1 shows that higher hydraulic head (pressure) increases are to be expected for low values of hydraulic conductivity and specific storage. Therefore, the first simulation of deep fluid injection was run considering the lowermost limit of characteristic values. Because the two other wells with analyzed cores in the Wabamun-Winterburn interval (7-29-65-7-W5M and 13-6-65-8-W5M) are well outside the modelled area, they were not considered in the determination of characteristic values to be used in numerical simulations except for the Upper Nisku aquifer, for which no information whatsoever is available at the injection well. For the Upper Winterburn and Blue Ridge aquifers, for which there are no data, the values characteristic for the Wabamun aquifer were considered representative as well. Table 2 presents the values for permeability and specific storage used in the first numerical simulation. The horizontal component of permeability, k_h, was computed according to the relation:

$$k_h = (k^2_{max} + k^2_{90})^{1/2} \qquad (4).$$

A steady-state simulation was run first with the lowermost limit of characteristic values for the hydraulic parameters K and Ss, and with the highest rate of injection during the 70-day period, $Q = 550\ m^3/day$ (1651 m^3 for 3 days). A steady-state simulation is equivalent to the end of a transient simulation of injecting continuously at a constant rate over a period of time of the order of 10^2 - 10^4 years. The results of the steady-state simulation have shown that:

1) the effects of injection do not propagate to the edges of the modelled area, therefore the results of the transient simulations will not be unduly affected (constrained) by the imposed boundary conditions; and
2) very little effects propagate through the Calmar aquitard to the underlying formations, which shows that the system being modelled for the 70-day period can be safely reduced from six layers to four or even three.

Table 2: Values of permeability and specific storage used in numerical simulations of injection at the well CSL Ethel 13-6-67-8W5M at the Swan Hills facility of the Alberta Special Waste Management Corporation.

Hydrostratigraphic Unit	First Simulation k_h (m^2)	First Simulation k_v (m^2)	First Simulation Ss (m^{-1})	Second Simulation k_h (m^2)	Second Simulation k_v (m^2)	Second Simulation Ss (m^{-1})
Wabamun	$5.3\text{x}10^{-15}$	$1.0\text{x}10^{-15}$	$1.2\text{x}10^{-4}$	$1.2\text{x}10^{-14}$	0.95x10-14	$3.2\text{x}10^{-4}$
Upper Winterburn	$5.3\text{x}10^{-15}$	$1.0\text{x}10^{-15}$	$1.2\text{x}10^{-4}$	$5.5\text{x}10^{-14}$	$1.05\text{x}10^{-14}$	$1.2\text{x}10^{-4}$
Blue Ridge	$5.3\text{x}10^{-15}$	$1.0\text{x}10^{-15}$	$1.2\text{x}10^{-4}$	$5.5\text{x}10^{-14}$	$1.05\text{x}10^{-14}$	$1.2\text{x}10^{-4}$
Calmar	$2.5\text{x}10^{-17}$	$1.0\text{x}10^{-17}$	$1.2\text{x}10^{-4}$	$2.5\text{x}10^{-17}$	$1.00\text{x}10^{-17}$	$1.2\text{x}10^{-4}$
Upper Nisku	$3.8\text{x}10^{-15}$	$0.7\text{x}10^{-15}$	$1.2\text{x}10^{-4}$			
Lower Nisku	$2.0\text{x}10^{-17}$	$1.0\text{x}10^{-17}$	$1.2\text{x}10^{-4}$			

It should be stressed here that these results were obtained with the most unfavorable and unrealistic combination of possible values of hydraulic parameters, rate of injection, and duration (time --> ∞).

Based on the results of the steady state simulation, the modelled interval was reduced to four layers: Calmar aquitard, Blue Ridge aquifer, Upper Winterburn aquifer and Wabamun aquifer. The total number of nodes and elements was reduced this way to 2160 and 1664, respectively, resulting in significant savings in computer resources for the transient simulation of deep injection. The variation during the 70-day period of the bottomhole pressure at the injection node is presented in table 3 and figure 4.

The second simulation of injection was run for the same four layer model, with values for the hydraulic parameters K and Ss at their upper limit. Because the values for permeability were obtained from drillstem tests (bulk permeability), they were decomposed into horizontal and vertical components assuming the same anisotropy k_h/k_v as in the case of the values obtained from core analyses. Regional values were considered for the specific storage Ss (Basin Analysis Group, 1985). The values of hydraulic parameters used in the second simulation are presented in table 2, while the results of the simulation (pressure variation) are shown in table 3 and figure 4.

Table 3: Injection rates and computed bottomhole pressures at the Swan Hills facility of Alberta Special Waste Management Corporation during a 70-day period in 1988.

Time step	End of Injection period	Injection rate (m^3/3d)	Computed pressure (kPa)	
			Minimum permeability	Maximum permeability
0	April 22	0.00	15359.00	15359.00
1	April 24	458.00	17488.75	15843.03
2	April 27	399.00	18477.50	15870.79
3	April 30	421.00	19201.38	15908.65
4	May 3	811.00	21485.64	16333.04
5	May 6	700.00	22365.89	16298.60
6	May 9	1075.00	24699.98	16699.34
7	May 12	1260.00	27008.57	16974.71
8	May 15	447.00	24682.82	16178.33
9	May 18	1139.00	26622.65	16773.31
10	May 21	1089.00	27576.38	16822.85
11	May 24	1080.00	28161.05	16831.68
12	May 27	898.00	27723.53	16646.86
13	May 30	1254.00	29176.39	16992.66
14	June 2	1651.00	31920.73	17476.00
15	June 5	1476.00	32787.84	17388.39
16	June 8	900.00	30710.18	16777.13
17	June 11	1009.00	30064.09	16784.49
18	June 14	282.00	26325.80	16009.99
19	June 17	198.00	23729.88	15774.85
20	June 20	1040.00	26055.92	16605.07
21	June 23	881.00	26620.88	16579.56
22	June 26	1040.00	27682.81	16752.51
23	June 29	1065.00	28430.53	16814.41

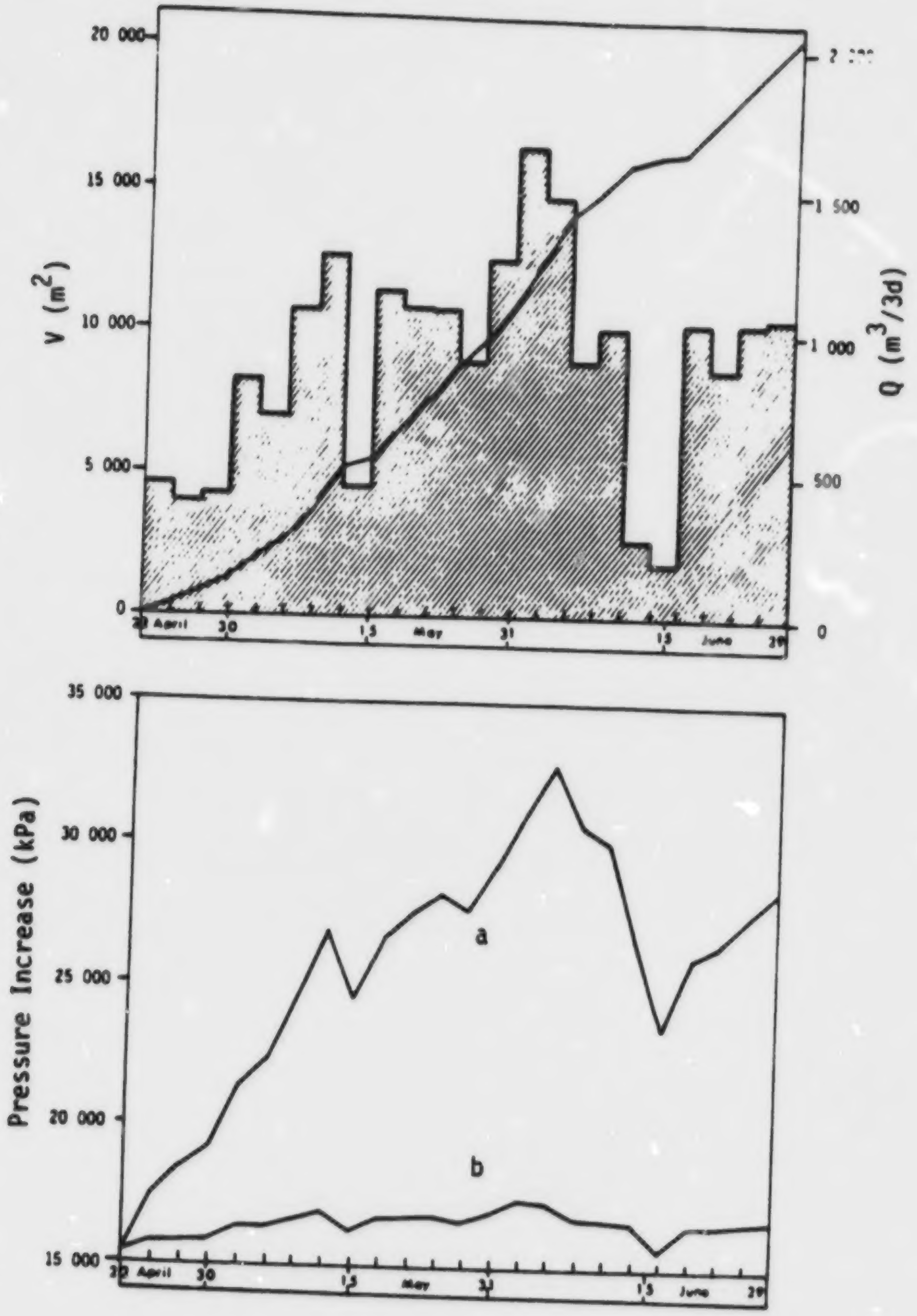

Figure 4: Variation of computed bottomhole pressure at the deep injection well at the Swan Hills facility of the Alberta Special Waste Management Corporation for a 70-day period in 1988, assuming: a) low values of hydraulic parameters; and b) high values of hydraulic parameters.

Comparing the variation of computed bottomhole pressure for the two cases (lower and upper limit of hydraulic parameters), it can be seen that the pressure buildup is higher in the first case than in the second by a factor of nine on average, which is expected because of lower values of hydraulic conductivity (permeability) by a factor of about ten. Also, the pressure variation follows more closely the variation of the injection rate in the case of low values of hydraulic parameters than in the case of high values. This is expected too, because, in fact, only the permeability has values greater by about one order of magnitude in the second case than in the first. The value of the specific storage differs by a factor of less than 3 for the Wabamun aquifer, being the same in both cases for all other hydrostratigraphic units. Accordingly, the aquifer diffusivity (K/Ss) has higher values in the second case than in the first. A pressure wave created by variations in the injection rate will dissipate more rapidly in the second case (high diffusivity) than in the first case (low diffusivity). As a result, the pressure drops when the rate of injection decreases. In the first case (low diffusivity), the pressure drops only when there are significant reductions in the injection rate.

The results of the above two simulations of deep injection show that the response of the system depends significantly on the actual hydraulic properties of the host zone. Given the scarcity of data and the uncertainty associated with the estimation of values for these parameters, these simulations are only indicative of a possible range of variation of the bottomhole pressure. It should be kept in mind also that the values obtained through numerical simulations are in fact representative at a radius of equivalence from the well, in this case estimated to be 3.6 m. A history match between computed and measured bottomhole pressure values could provide a means for a better estimation of the aquifer hydraulic properties.

CONCLUSIONS

The Basin Analysis Group of the Alberta Geological Survey, Alberta Research Council, was asked to simulate numerically the variation during a 70-day period in 1988 of the bottomhole pressure at the deep injection well situated at the Swan Hills facility of the Alberta Special Waste Management Corporation.

The geophysical logs of the injection well were interpreted in order to delineate the hydrostratigraphic succession, based on lithology and generally known rock properties. Injection takes place in the Blue Ridge Fm. of the Winterburn Group, Upper Devonian. Six hydrostratigraphic units were recognized between the thick regional aquitards (Ireton and Exshaw) underlying and overlying the Wabamun-Winterburn succession. They are, in ascending order: Lower Nisku aquitard, Upper Nisku aquifer, Calmar aquitard, Blue Ridge aquifer, Upper Winterburn aquifer and Wabamun aquifer.

Data from core analyses and drillstem tests at the injection well provided the basis for estimating the values of hydraulic parameters characterizing the hydrostratigraphic units in the succession to be modelled. No single, unique value could be determined for permeability, porosity, hydraulic conductivity and specific storage, but rather a range of possible characteristic values bounded by a lower and an upper limit was used.

Two numerical simulations were performed using the finite element model FE3DGW, one with the lower limit of characteristic values and one with the upper limit. A steady-state simulation with the lower values has shown that practically no pressure effects propagate below the Calmar aquitard, allowing a reduction to four in the number of hydrostratigraphic units to be modelled. The two transient simulations of injection at given rates during the 70-day period show higher pressure buildups in the case of lower values for hydraulic parameters. The pressure variation follows more closely the variation of injection rate in the case of higher values of hydraulic parameters because of higher aquifer diffusivity which allows a more rapid dissipation of the pressure wave created by injection. By comparing the computed with the measured bottomhole pressures for the 70-day period, and by performing a few additional simulations if needed, the actual values of hydraulic parameters for the host zone can be better estimated using a history match procedure.

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APPENDIX

This appendix presents, in table and graph form without comments, the results of core data processing for hydraulic parameters (components of the permeability tensor, and porosity) at the injection well (CSL Ethel 13-6-67-8W5M) at the Swan Hills facility of the Alberta Waste Management Corporation, and at two other close wells. Comments are found in the chapter "Hydraulic Parameters" of the report.

Table A1: Characteristic values of maximum horizontal permeability, k_{max}, from core analyses in the Wabamun-Winterburn interval, at the injection site and at wells within a two townships radius (values in units of $10^{-15} m^2$).

UNIT	WELL	NO. OF VALUES	MINIMUM VALUE	HARMONIC AVERAGE	GEOMETRIC AVERAGE	MEDIAN VALUE	WEIGHTED AVERAGE	ARITHMETIC AVERAGE	MAXIMUM VALUE
WABAMUN	INJECTION	90	<0.01	0.213	3.352	4.000	12.520	13.417	105.352
CALMAR	INJECTION	2	<0.01	0.015	0.018	-	0.022	0.020	0.030
NISKU	INJECTION	6	<0.01	0.015	0.015	-	0.015	0.016	0.020
	66-6-07	54	<0.01	0.107	2.122	4.200	12.125	12.640	74.658
	65-6-08	22	<0.01	0.312	0.136	0.200	0.414	0.568	3.140

Table A2: Characteristic values of horizontal permeability at 90 degrees to maximum horizontal permeability, k_{90}, from core analyses in the Wabamun-Winterburn interval, at the injection site and at wells within a two townships radius (values in units of $10^{-15} m^2$).

UNIT	WELL	NO. OF VALUES	MINIMUM VALUE	HARMONIC AVERAGE	GEOMETRIC AVERAGE	MEDIAN VALUE	WEIGHTED AVERAGE	ARITHMETIC AVERAGE	MAXIMUM VALUE
WABAMUN	INJECTION	93	<0.01	0.167	2.605	3.5	8.790	9.580	62.100
CALMAR	INJECTION	2	<0.01	0.014	0.014	-	0.016	0.015	0.020
	INJECTION	5	<0.01	0.011	0.012	-	0.012	0.012	0.020
NISKU	65-5-07	64	<0.01	0.060	1.173	2.8	7.710	8.047	63.211
	65-5-08	21	<0.01	0.017	0.053	0.01	0.206	0.342	2.674

Table A3: Characteristic values of vertical permeability, k_v, from core analyses in the Wabamun-Winterburn interval, at the injection site and at wells within a two townships radius (values in units of $10^{-15} m^2$).

UNIT	WELL	NO. OF VALUES	MINIMUM VALUE	HARMONIC AVERAGE	GEOMETRIC AVERAGE	MEDIAN VALUE	WEIGHTED AVERAGE	ARITHMETIC AVERAGE	MAXIMUM VALUE
WABAMUN	INJECTION	90	<0.01	0.070	0.887	1.060	5.152	5.790	49.333
CALMAR	INJECTION	2	<0.01	-	-	-	-	-	0.010
	INJECTION	5	<0.01	-	-	-	-	-	0.010
NISKU	66-5-07	64	<0.01	0.042	0.457	0.700	2.914	3.001	20.067
	65-5-08	21	<0.01	0.013	0.019	0.010	0.037	0.064	0.709

Table A4: Characteristic values of porosity from core analyses in the Wabamun-Winterburn interval, at the injection site and at wells within a two townships radius (values in percent).

UNIT	WELL	NO. OF VALUES	MINIMUM VALUE	HARMONIC AVERAGE	GEOMETRIC AVERAGE	MEDIAN VALUE	WEIGHTED AVERAGE	ARITHMETIC AVERAGE	MAXIMUM VALUE
WABAMUN	INJECTION	92	0.1	6.2	7.7	8.8	8.4	8.6	14.3
CALMAR	INJECTION	2	0.5	0.5	0.5	-	0.5	0.5	0.5
	INJECTION	5	0.1	0.8	0.9	-	1.1	1.0	1.7
NISKU	65-5-07	54	0.1	3.4	4.0	4.5	4.2	4.4	8.3
	65-5-08	22	0.1	1.4	1.8	2.2	1.9	2.2	6.2

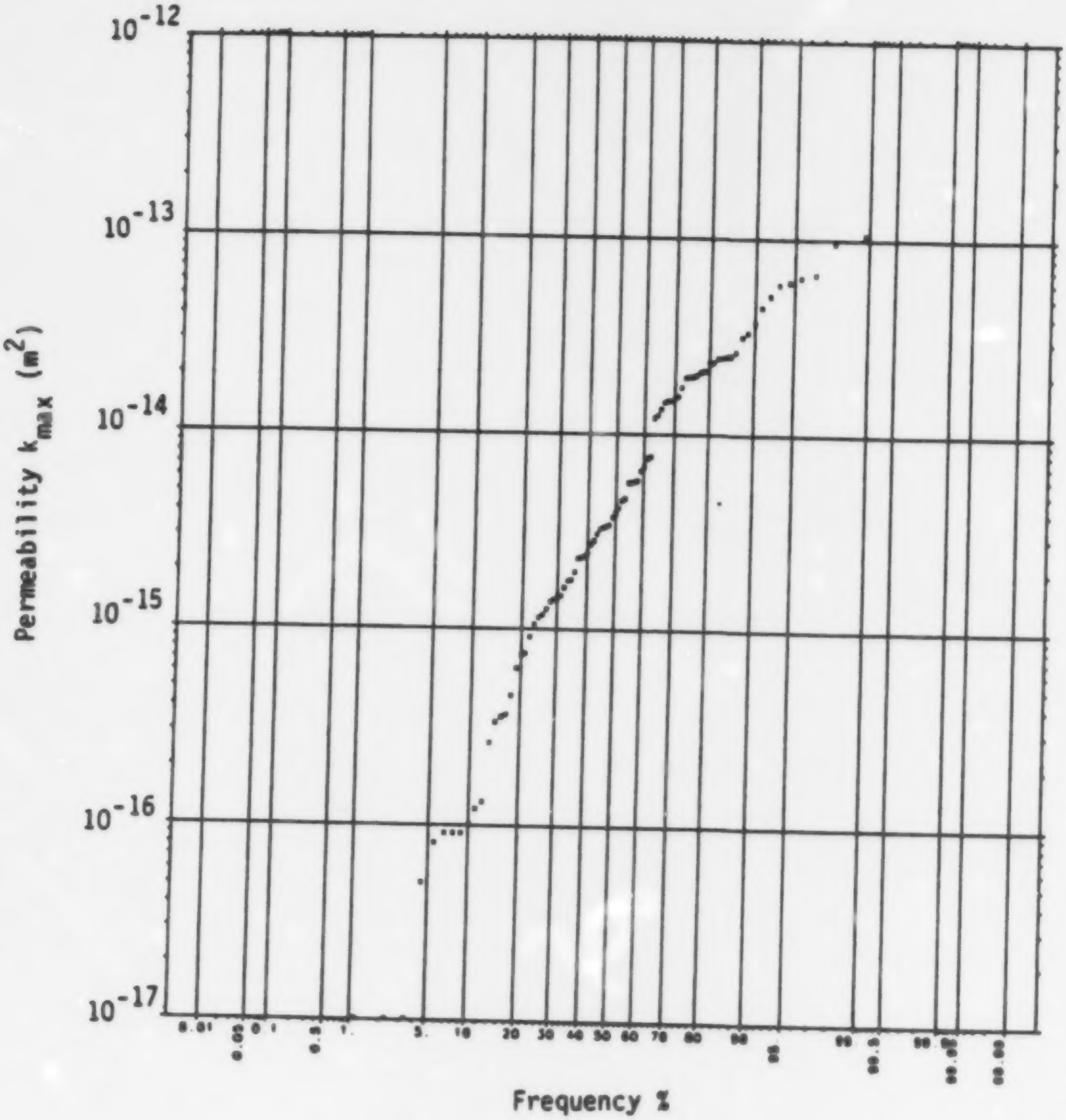

Figure A1: Frequency distribution of values of maximum horizontal permeability, k_{max}, in Wabamun Group, from core analyses at the injection well.

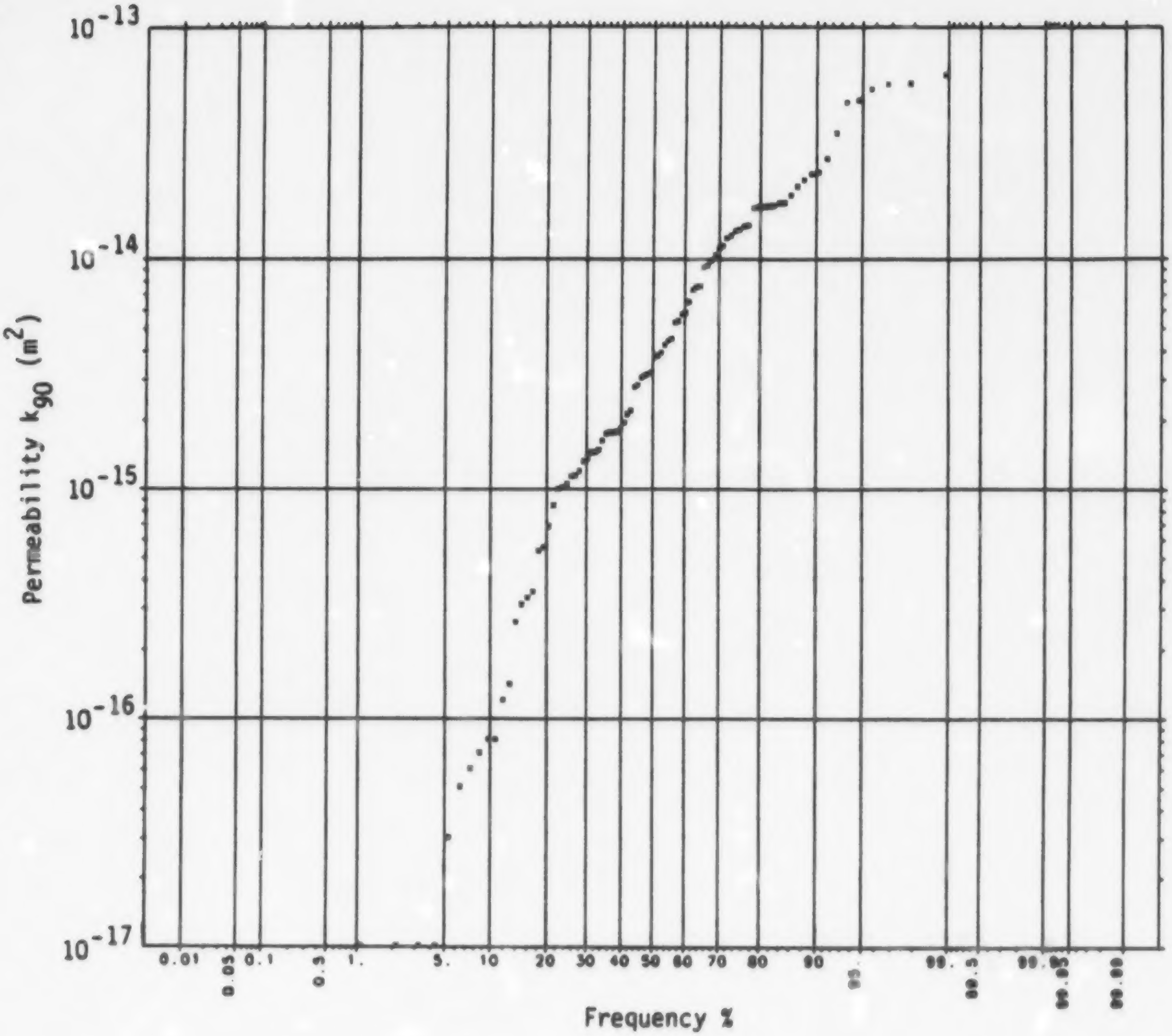

Figure A2: Frequency distribution of values of horizontal permeability at 90 degrees to the maximum horizontal permeability, k_{90}, in Wabamun Group, from core analyses at the injection well.

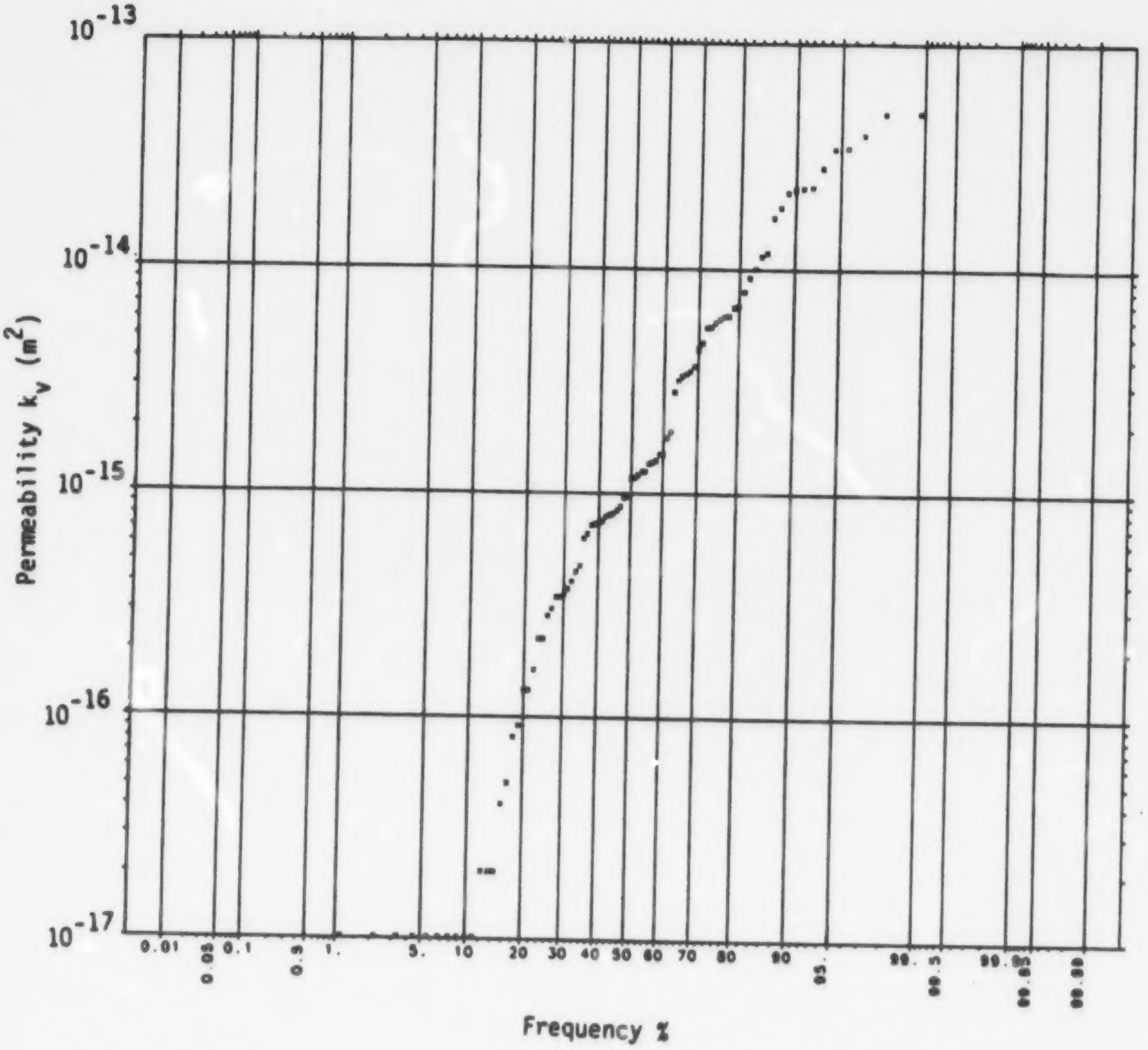

Figure A3: Frequency distribution of values of vertical permeability, k_v, in Wabamun Group, from core analyses at the injection well.

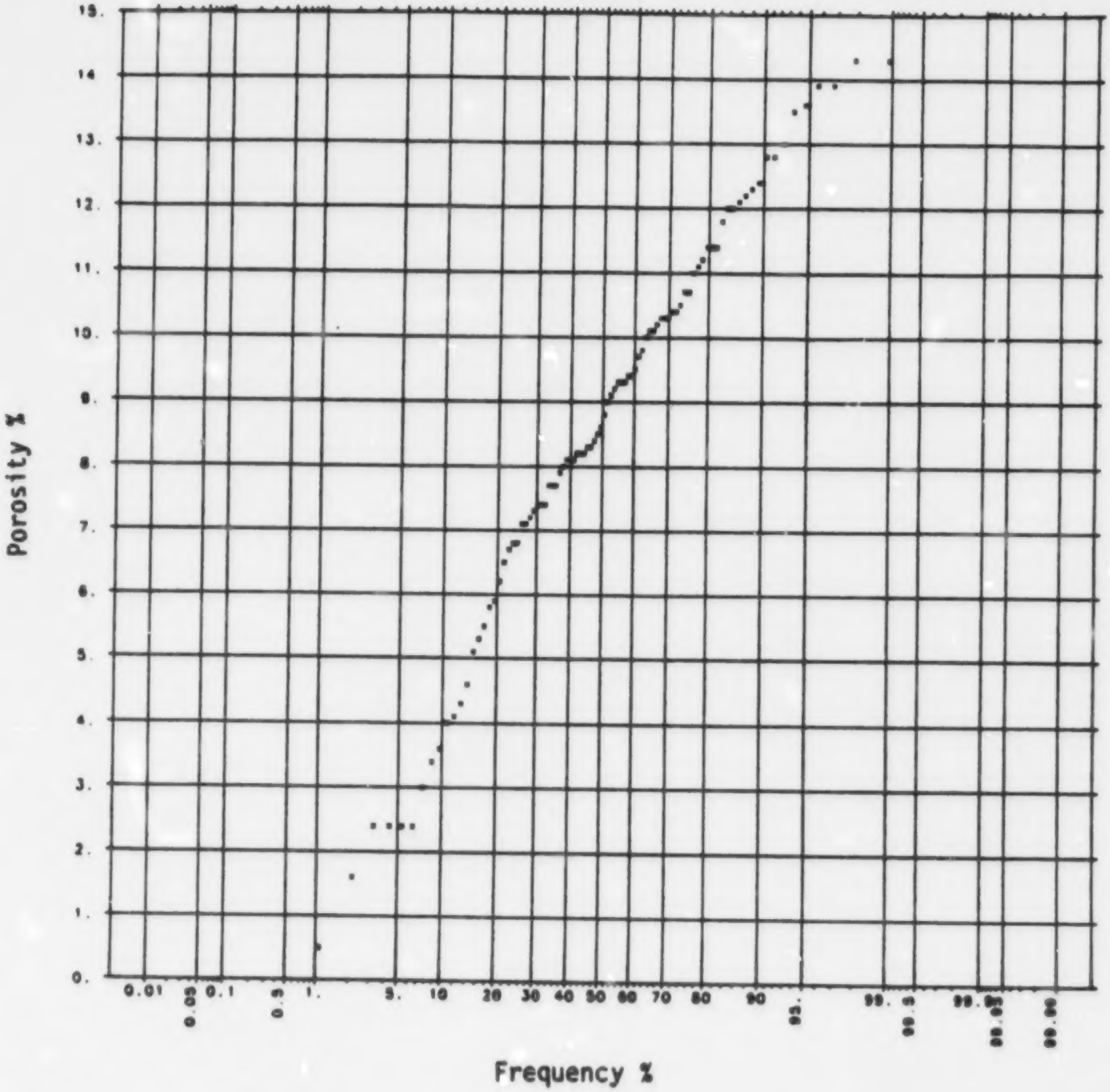

Figure A6: Frequency distribution of values of porosity in Wabamun Group, from core analyses at the injection well.

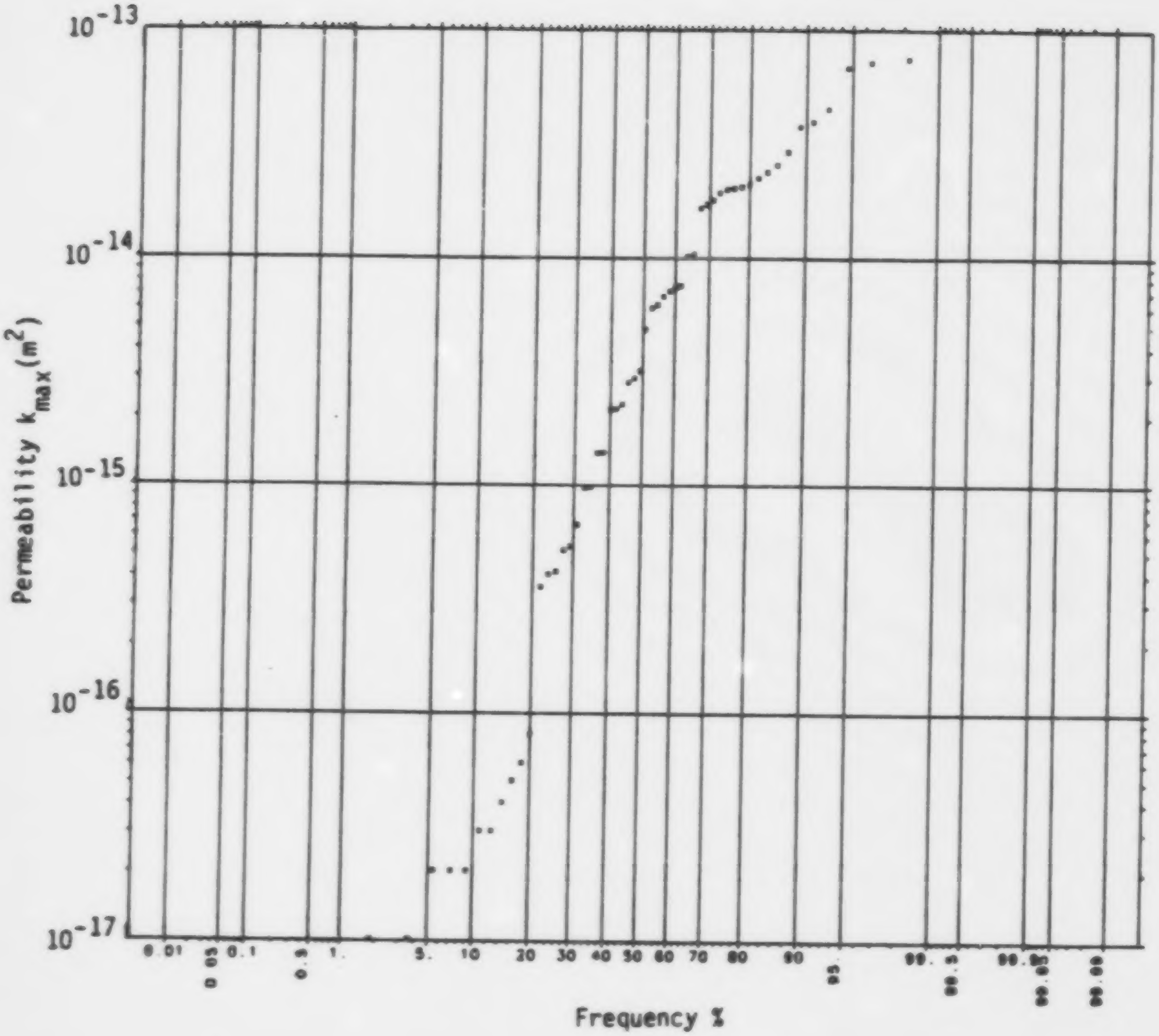

Figure A5: Frequency distribution of values of maximum horizontal permeability, k_{max}, in Nisku Fm., from core analyses at the well 7-29-65-7W5.

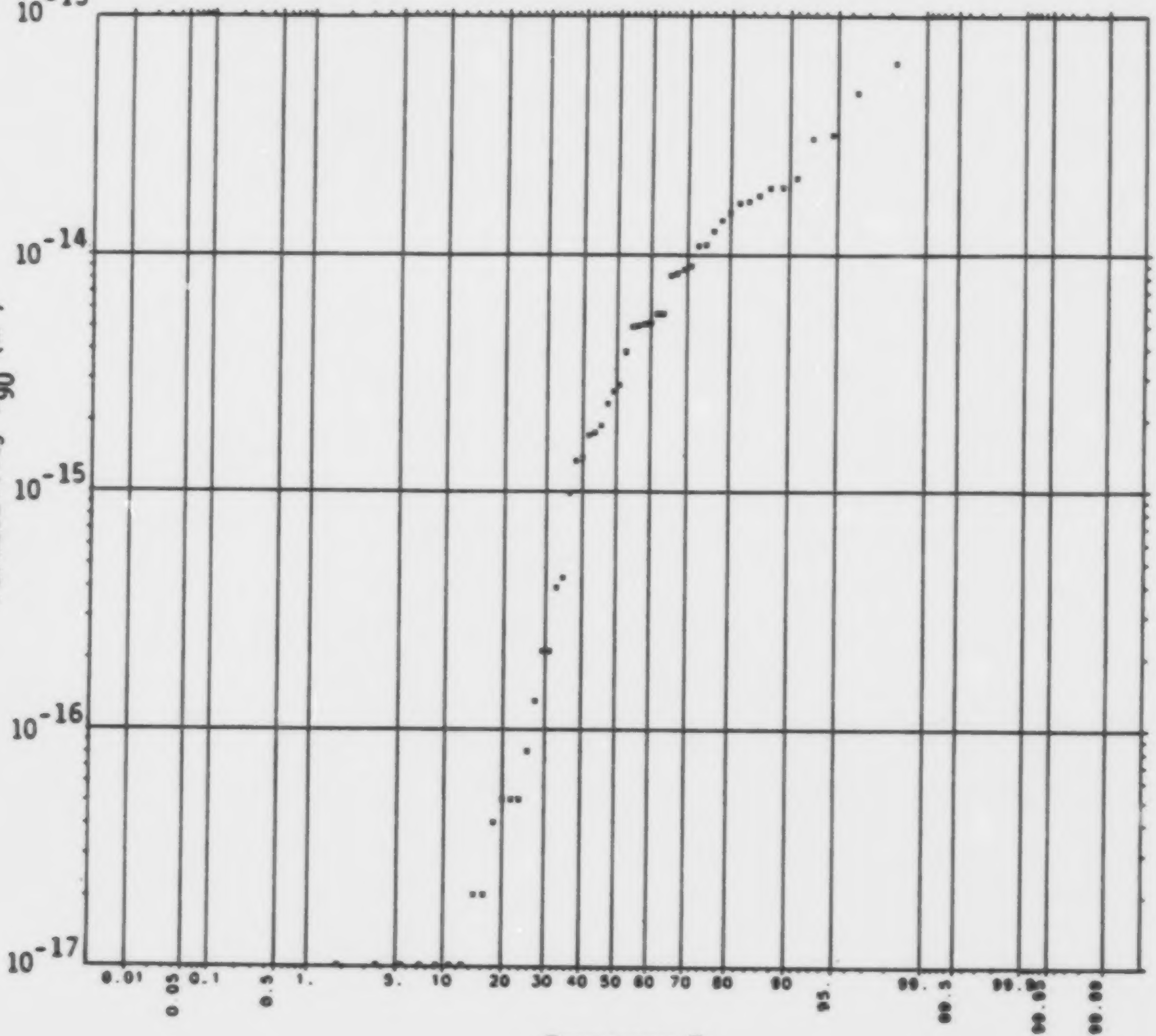

Figure A6: Frequency distribution of values of horizontal permeability at 90 degrees to the maximum horizontal permeability, k_{90}, in Nisku Fm., from core analyses at the well 7-29-65-7W5.

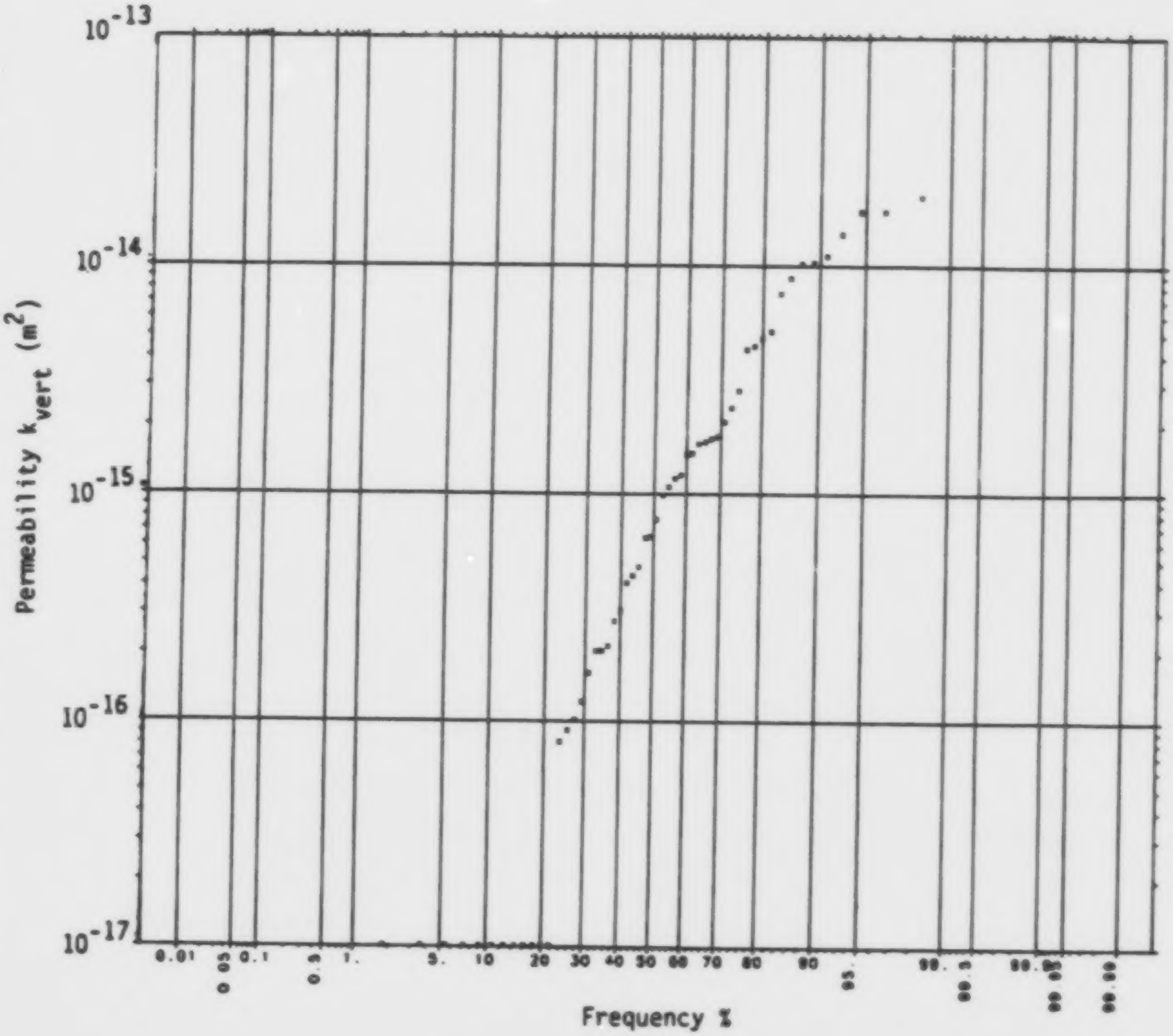

Figure A7: Frequency distribution of values of vertical permeability, k_v, in Nisku Fm., from core analyses at the well 7-29-65-7W5.

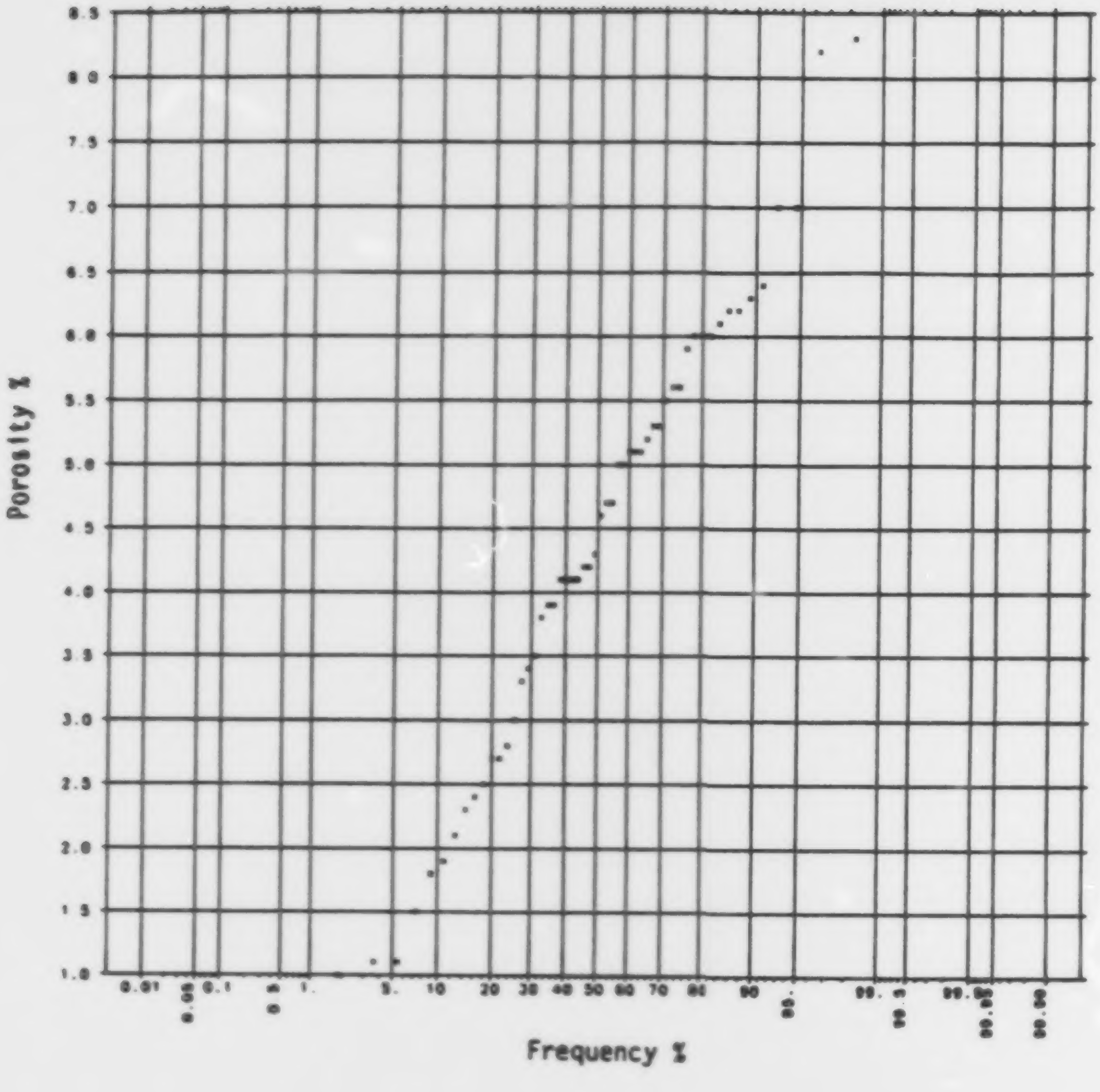

Figure A8: Frequency distribution of values of porosity in Nisku Fm., from core analyses at the well 7-29-65-7W5.

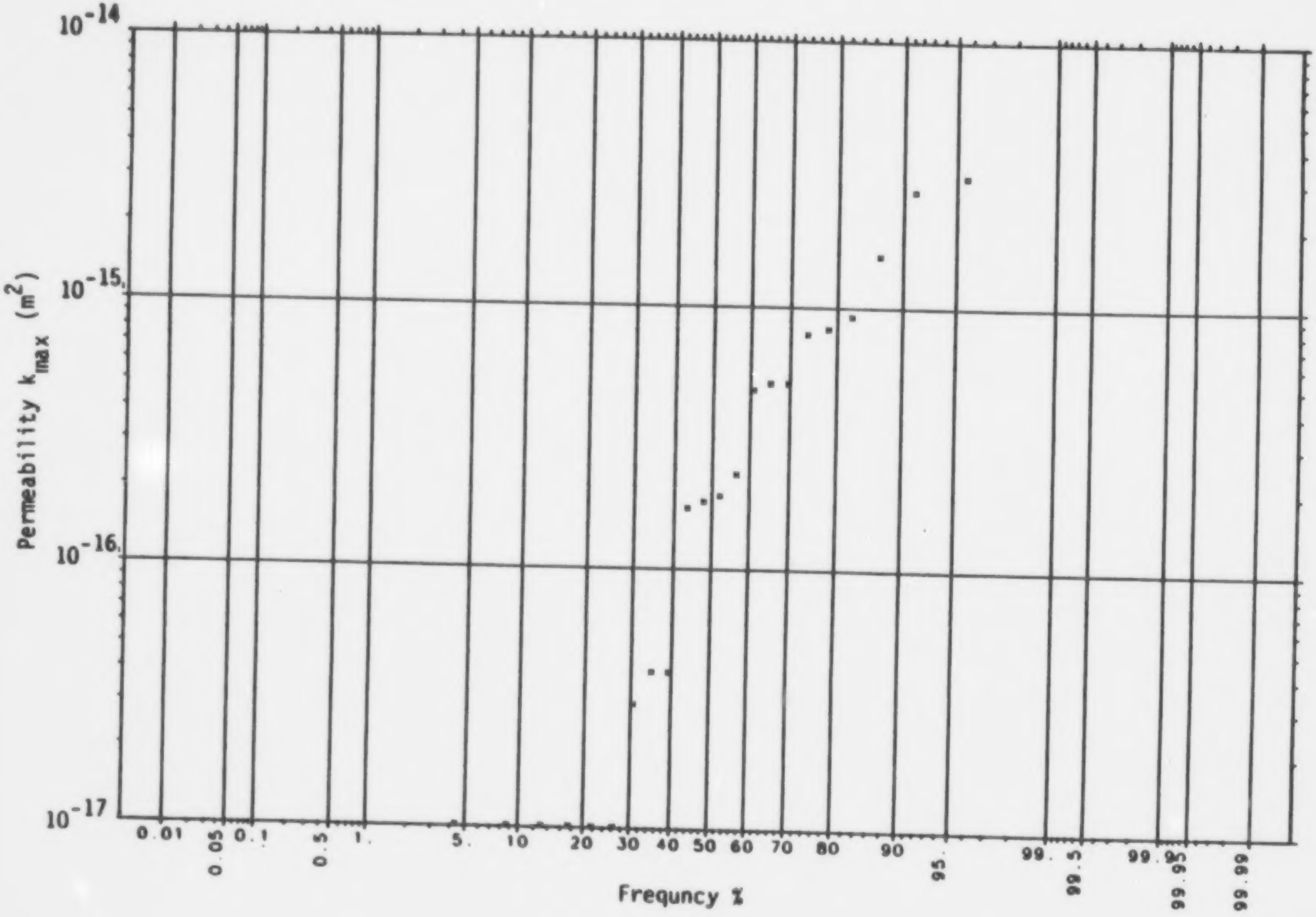

Figure A9: Frequency distribution of values of maximum horizontal permeability, k_{max}, in Nisku Fm., from core analyses at the well 2-34-65-8W5.

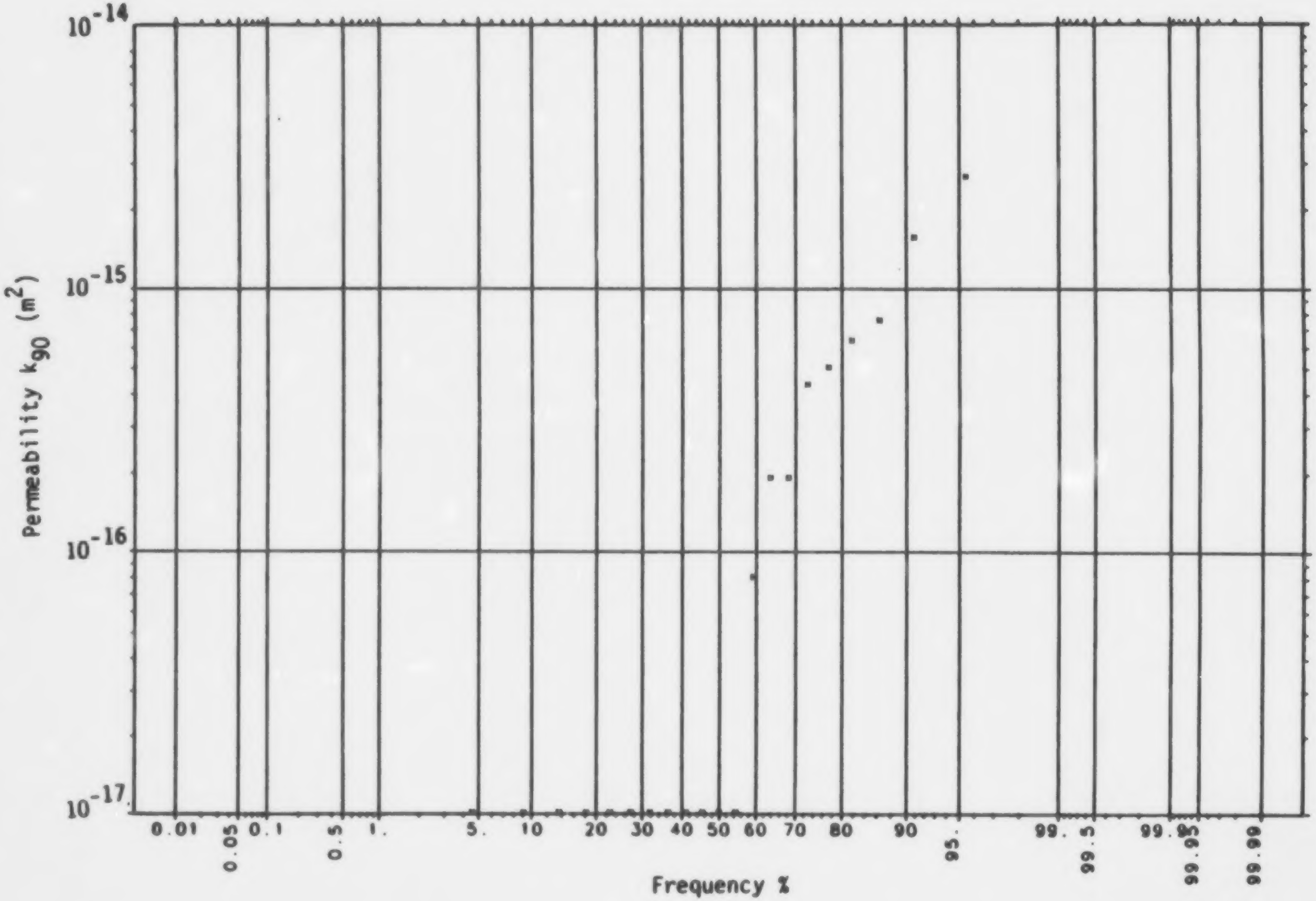

Figure A10: Frequency distribution of values of horizontal permeability at 90 degrees to the maximum horizontal permeability, k_{90}, in Nisku Fm., from core analyses at the well 2-34-65-8W5.

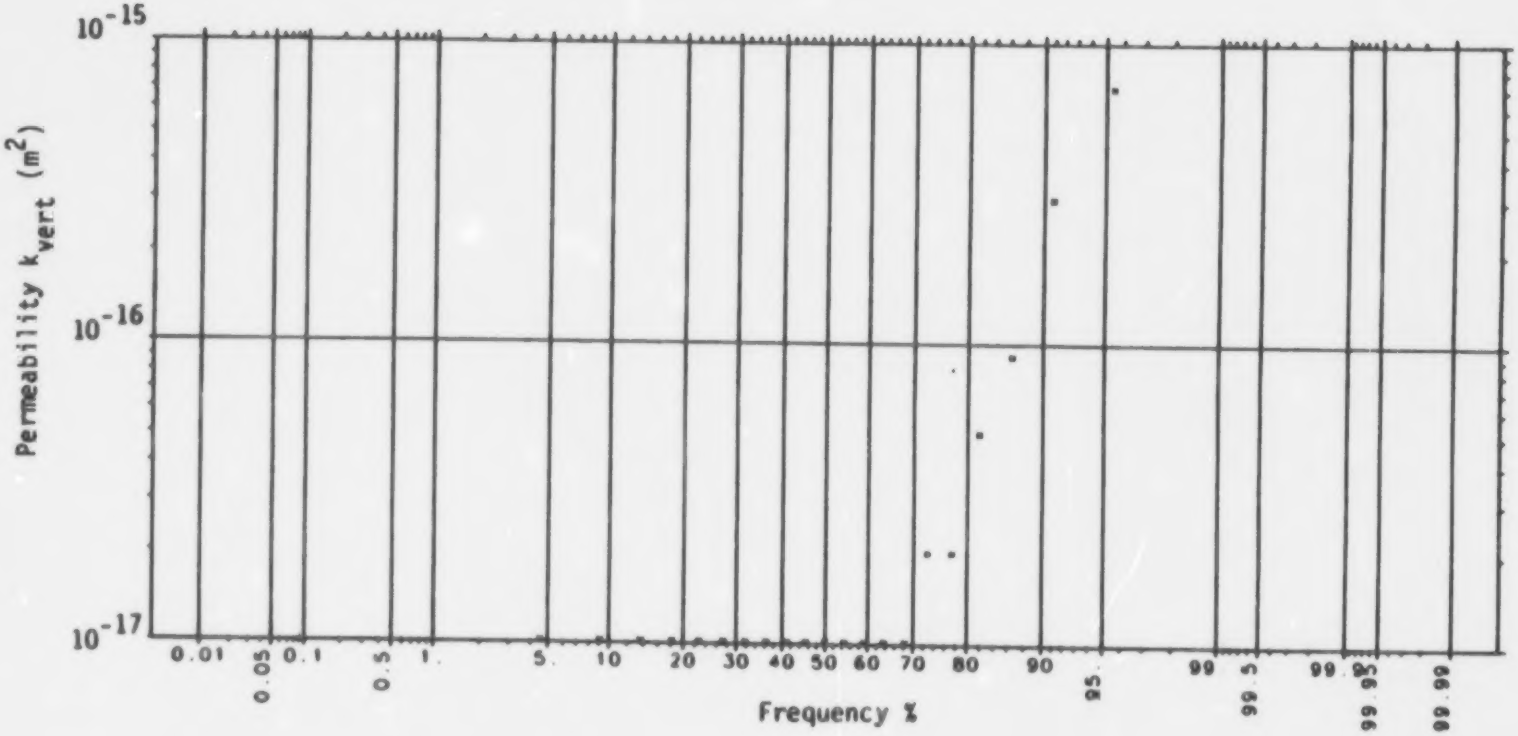

Figure A11: Frequency distribution of values of vertical permeability, k_v, in Nisku Fm., from core analyses at the well 2-34-65-8W5.

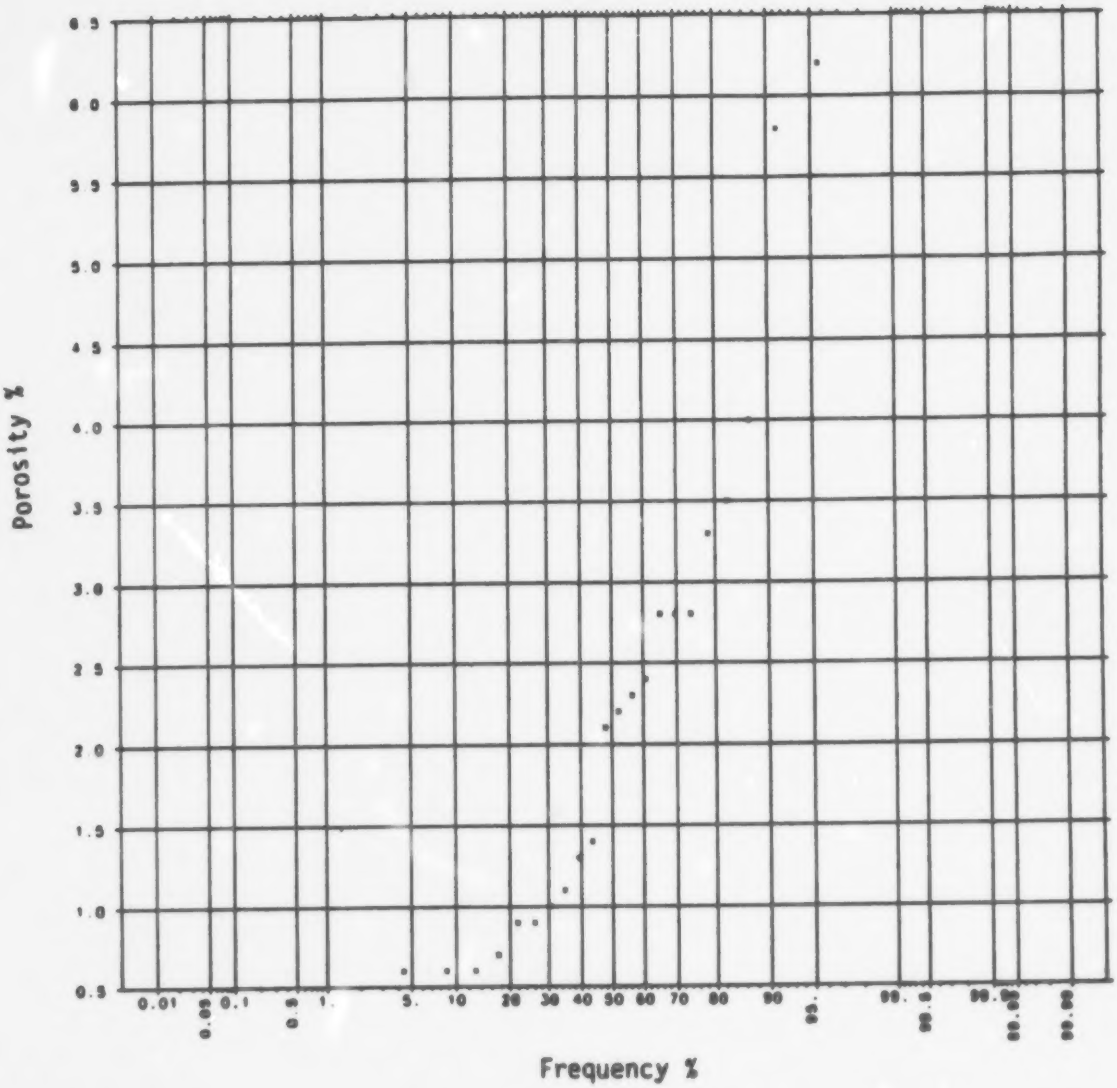

Figure A12: Frequency distribution of values of porosity in Nisku Fm., from core analyses at the well 2-34-65-8W5.

Addendum to the Report
Numerical Simulation of Deep Fluid Injection at the Swan Hills Facility of the Alberta Special Waste Management Corporation

Prepared for

Stanley Associates Engineering Ltd.

by

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1988-12-23

On November 15, 1988, the Basin Analysis Group of the Alberta Geological Survey, Alberta Research Council, delivered a report to Stanley Associates Engineering Ltd. (SAEL) regarding numerical simulations of deep fluid injection during the period April 22 - June 29, 1988, at the Swan Hills Facility of the Alberta Special Waste Management Corporation. Injection takes place in the Blue Ridge Formation of the Winterburn Group. The deep hydrostratigraphy was delineated at the well site, and four hydrostratigraphic units were identified for numerical simulation of deep fluid injection: Calmar aquitard, Blue Ridge aquifer, Upper Winterburn aquifer and Wabamun aquifer. Data from core analyses and drillstem tests were analyzed and processed in order to determine values for permeability, porosity, hydraulic conductivity and specific storage. Because no unique value could be determined for any hydraulic parameter, two simulations were performed, one with a combination of low values for hydraulic parameters, and one with a combination of high values.

On December 5, 1988, the Basin Analysis Group was approached by SAEL to perform another two numerical simulations using the same finite element grid, one simulation with low and one with high values for hydraulic parameters, to cover the period October 18 - November 30, 1988. The results of these two simulations form the content of the present addendum to the report delivered to SAEL on November 15, 1988. The interpretation of the results and the conclusions are basically the same as in the initial report, thus this addendum presents only the simulated pressure buildups in tabular and graphical form. Because the initial bottomhole pressure was not indicated by SAEL, the results are presented as pressure increase instead of total pressure. The simulations were possible even without knowing the initial pressure because of the linearity of the equation for fluid flow in porous media (eq. 1 in the report), which allows a linear superposition of effects. Thus, the simulated pressure values can be calculated by adding the computed pressure increases to an initial pressure value.

Table 1: Injection rates and computed increase of bottomhole pressure at the Swan Hills facility of Alberta Special Waste Management Corporation for the period Oct. 18 - Nov. 30, 1988.

Time step	End of Injection period	Injection rate (m^3/d)	Computed pressure increase (kPa)	
			Minimum permeability	Maximum permeability
1	Oct. 18	234.00	1508.78	557.89
2	19	256.00	2850.30	802.46
3	20	227.00	3738.10	831.69
4	21	235.00	4509.36	874.66
5	22	293.00	5513.02	1036.33
6	23	226.00	5897.38	938.92
7	24	227.00	6230.53	916.25
8	25	210.00	6405.93	870.93
9	26	147.00	6158.42	707.10
10	27	196.00	6295.27	768.12
11	28	188.00	6366.69	766.95
12	29	229.00	6700.92	864.75
13	30	150.00	6469.30	710.54
14	31	75.00	5813.80	481.67
15	Nov. 1	185.00	6011.47	663.06
16	2	208.00	6322.15	773.91
17	3	229.00	6710.33	863.48
18	4	295.00	7451.38	1055.07
19	5	276.00	7926.38	1079.98
20	6	270.00	8276.50	1081.55
21	7	280.00	8631.72	1110.79
22	8	232.00	8617.30	1009.55
23	9	220.00	8541.57	949.02
24	10	185.00	8266.99	844.35
25	11	212.00	8232.36	871.32
26	12	299.00	8772.99	1085.08
27	13	198.00	8558.05	917.24
28	14	284.00	8950.15	1069.58
29	15	290.00	9307.04	1135.02
30	16	288.00	9585.94	1156.11
31	17	204.00	9275.06	966.87
32	18	217.00	9121.04	935.38
33	19	198.00	8882.76	876.33
34	20	209.00	8769.55	880.15
35	21	211.00	8695.98	883.88
36	22	225.00	8730.41	917.43
37	23	218.00	8715.01	911.84
38	24	201.00	8595.42	869.95
39	25	288.00	9063.46	1063.11
40	26	293.00	9469.40	1140.61
41	27	293.00	9796.07	1171.80
42	28	302.00	10119.60	1208.40
43	29	223.00	9874.26	1035.94
44	30	215.00	9635.28	960.60

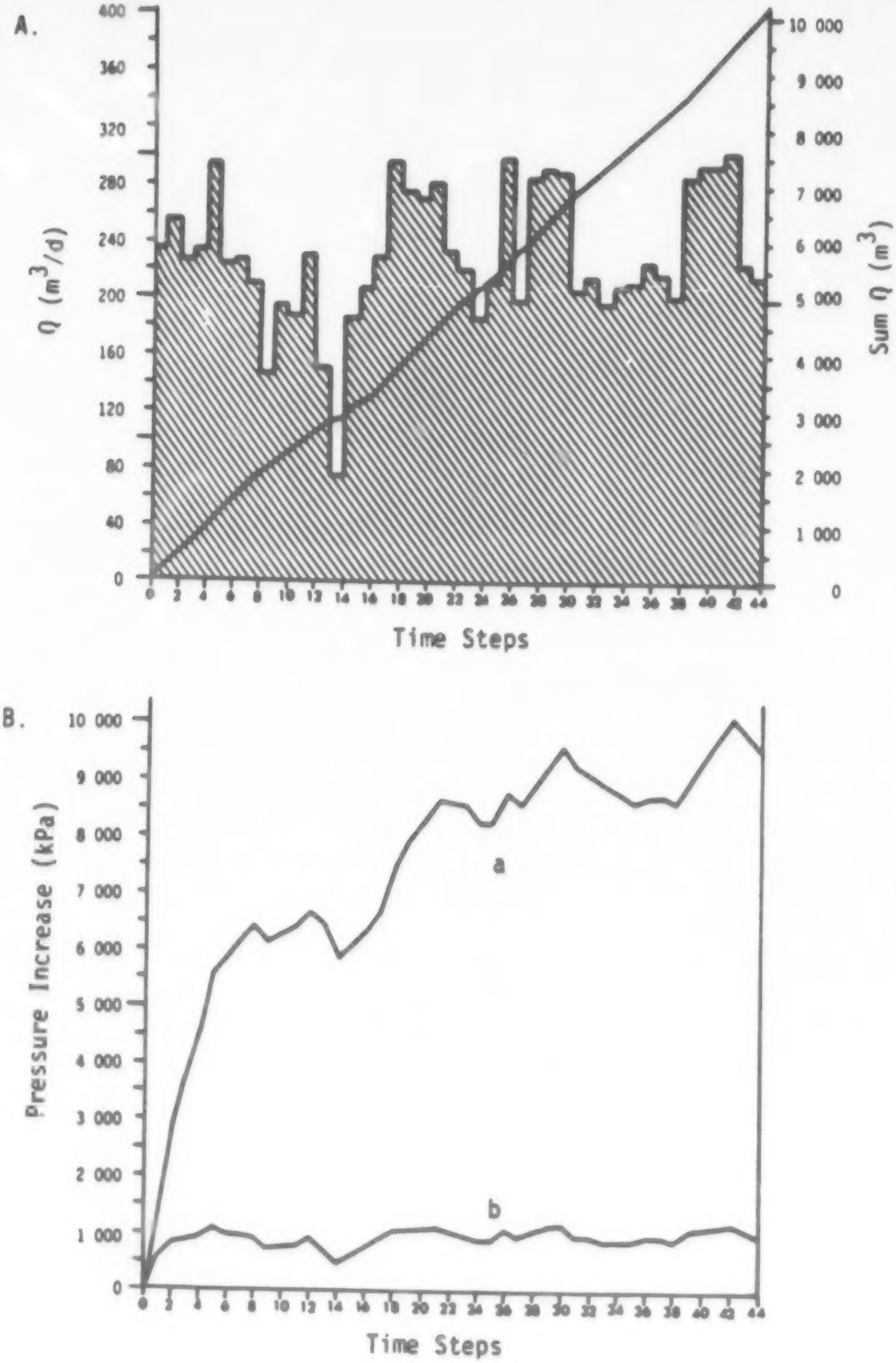

Figure 1: A. Injection rates and cumulated injected volumes during the period October 14 - November 30, 1988, at the deep well at the Swan Hills facility of the Alberta Special Waste Management Corporation.

B. Corresponding computed increase of bottomhole pressure assuming: (a) low values of hydraulic parameters; (b) high values of hydraulic parameters.

APPENDIX D

POTENTIAL MONITORING WELLS

AREA 1

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
010-01-056-01W4M	ARIES JOHN LAKE 10-1	GASWELL
015-03-056-01W4M	NEWEX JOHN LAKE 15-3	GASWELL
06-06-056-01W4M	ANDERSON ET AL ROCK ISLAND 6-6	S.I. GASWELL
07-010-056-01W4M	AMOCO JOHN LAKE 7-10	S.I. GASWELL
010-011-056-01W4M	DOME AQ JOHN LAKE EX 10-11	S.I. OILWELL
010-013-056-01W4M	HB HAZELDINE 10-13	S.I. GASWELL
014-016-056-01W4M	TEXACO JOHN LAKE 14-16	S.I. GASWELL
09-018-056-01W4M	TEXACO JOHN LAKE 9-18	S.I. GASWELL
015-019-056-01W4M	TEXACO JOHN LAKE 15-19	S.I. GASWELL
014-021-056-01W4M	TEXACO FROG LAKE 14-21	S.I. GASWELL
06-022-056-01W4M	POCO JOHN LAKE 6-22	S.I. GASWELL
010-023-056-01W4M	HB JOHN LAKE 10-23	S.I. GASWELL
05-027-056-01W4M	TEXACO JOHN LAKE 5-27	S.I. GASWELL
014-029-056-01W4M	TEXACO FROG LAKE 14-29	S.I. GASWELL
011-034-056-01W4M	NEWEX JOHN LAKE 11-34	GASWELL

STATUS OF POTENTIAL MONITORING WELLS

AREA 2

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
010-01-055-06 W4M	WESTMIN LINDBERGH EX 10-1	EXPERIMENTAL WELL
07-02-055-06 W4M	DOME ET AL LINGBERGH 7-2	OILWELL
02-04-055-06 W4M	DOME ET AL LIND 2-4	GASWELL
03A-05-055-06 W4M	WESTMIN LINGBERGH 3A-5	OILWELL
07A-08-055-06 W4M	HB IRISH 7A-8	GASWELL
010A-09-055-06 W4M	PCP LINDBERGH 10A-9	OILWELL
07A-010-055-06 W4M	DOME ET AL LINDBERGH 7A-10	OILWELL
02A-011-055-06 W4M	DOME ET AL LINDBERGH 2A-11	OILWELL
015A-012-055-06 W4M	DOME ET AL LINDBERGH 15A-12	IND OILWELL
07A-013-055-06 W4M	WESTN LIND EX 7A-13	THI WELL
06A-014-055-06 W4M	PCP LINDBERGH 6A-14	OILWELL
010A-015-055-06 W4M	WESTMIN LINGBERGH 10A-15	OILWELL
016-016-055-06 W4M	AMOCO 02 LINDBERGH 16-16	OILWELL
016A-017-055-06 W4M	WESMIN LINDBERGH 16A-17	OILWELL
011-020-055-06 W4M	HDL AMOCO PEAT 11-20	GASWELL
04-021-055-06 W4M	BRASCAN LINDBERGH 4-21	OIL & GASWELL
01-022-055-06 W4M	AMOCO 01 LINDBERGH 1-22	OILWELL
06A-023-055-06 W4M	PCP LINDBERGH 6A-23	S.I. OILWELL
07-024-055-06 W4M	SULPETRO IRISH 7-24	S.I. GASWELL
010-025-055-06 W4M	DOME PCP LINDBERGH 10-25	OILWELL
01A-026-055-06 W4M	DOME LINDBERGH 1A-26	OILWELL
06B-027-055-06 W4M	WESTN LIND 6B-27	OILWELL
01-028-055-06 W4M	AMOCO LINDBERGH 1-28	SUSP HVY OILWELL
06-029-055-06 W4M	AMOCO B2 LINDBERGH 6-29	OILWELL
08-030-055-06 W4M	AMOCO B-9 LINDBERGH 8-30	OILWELL
05A-031-055-06 W4M	WESTMIN LINDBERGH 5A-31	OILWELL

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
06-032-055-06 W4M	AMOCO LINDBERGH 6-32	OILWELL
04A-033-055-06 W4M	DOME ET AL LINDBERGH 4A-33	OILWELL
010A-034-055-06 W4M	DOME ET AL LINDBERGH 10A-34	OILWELL
011-035-055-06 W4M	BRASCAN GEDEON 11-35	S.I. GASWELL
04A-036-055-06 W4M	DOME ET AL LINDBERGH 4A-36	OILWELL

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
11-01-056-06W4M	BRASCAN LINDBERGH 11-1	CR BIT PUMP
4A-02-056-06W4M	DOME ET AL LINDBERGH 4A-2	CR BIT PUMP
5A-03-056-06W4M	PCP LINDBERGH 5A-3	CR BIT PUMP
9-04-056-06W4M	AMOCO C-1 LINDBERGH 9-4	CR BIT PUMP
8A-05-056-06W4M	DOME ET AL LINDBERGH 8A-5	CR BIT PUMP
10-06-056-06W4M	BRIDGER AMOCO ELK POINT 10-6	GAS SUSP
10-07-056-06W4M	BRIDGER PCP ELK POINT 10-7	GAS FLOW
6-08-056-06W4M	SIEBENS ELK POINT 6-8	GAS CAPPED
7A-09-056-06W4M	DOME ET AL LINDBERGH 7A-9	CR BIT SUSP
10A-010-056-06W4M	DOME ET AL LINDBERGH 10A-10	CR BIT PUMP
7-011-056-06W4M	SULPETRO IRISH 7-11-56-6	CR BIT SUSP
4A-012-056-06W4M	DOME ET AL LINDBERGH 4A-12	CR BIT SUSP
6-013-056-06W4M	WESTMIN LINDBERGH 6-13	CR BIT PUMP
4A-014-056-06W4M	DOME ET AL LINDBERGH 4A-14	CR BIT PUMP
6A-015-056-06W4M	WESTMIN LINDBERGH A6A-15	CR BIT PUMP
9A-016-056-06W4M	DOME ET AL LINDBERGH 9A-16	CR BIT PUMP
10-017-056-06W4M	BRASCAN WEST MINES LIND 10-17	CR BIT SUSP
11-018-056-06W4M	AMOCO C-1 LINDBERGH 11-18	CR BIT PUMP
3A-019-056-06W4M	PCP LINDBERGH 3A-19	CR BIT ABD
1-021-056-06W4M	BRASCAN WEST MINES LIND 1-21	CR BIT PUMP
3A-022-056-06W4M	DOME ET AL LINDBERGH 3A-22	CR BIT PUMP
1A-023-056-06W4M	PCP LINDBERGH 1A-23	UND SUSP
16C-024-056-06W4M	DOME ET AL LINDBERGH 16C-24	OILWELL
7-025-056-06W4M	CANSALT ELK POINT 7-25	GASWELL
11-026-056-06W4M	CANSALT ELK POINT 11-26	GASWELL
8-027-056-06W4M	WESTMIN LINDBERGH 8-27	OILWELL

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
15-031-056-06W4M	ELK POINT NATURAL GAS # 4	GASWELL
10-033-056-06W4M	MILL CITY GRADE # 2	ABD GASWELL
16-034-056-06W4M	EPGL ELK POINT 16-34-56-6	GASWELL
11-035-056-06W4M	CANSALT ELK POINT 11-35	GASWELL

01/24/89

AREA 3

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
010-09-059-02 W4M	SUNCOR ET AL CHANDLER 10-9	S.I. GASWELL
011-05-059-02 W4M	WECO BUTTES SOARS 11-5	S.I. GASWELL
07-015-059-02 W4M	SUNCOR ET AL CHANDLER 7-15	S.I. GASWELL
014-018-059-02 W4M	WECO BUTTES SOARS 14-18	GASWELL
06-020-059-02 W4M	WECO BUTTES SOARS 11-19	S.I. GASWELL
010-024-059-02 W4M	AMOCO SOARS EX 10-24	EXPERIMENTAL WELL

STATUS OF POTENTIAL MONITORING WELLS

AREA 4

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
1A-02-058-04W4M	HUSKY FROG LAKE 1A-2	OILWELL
6-06-058-04W4M	CDNOXY LINDBERGH 6-6	S. I. GASWELL
6-07-058-04W4M	CS LIND 6-7	ABD
10-09-058-04W4M	CDNOXY LINDBERGH 10-9	S. I. GASWELL
15-011-058-04W4M	KISSINGER ALGAS LINDBERGH15-11	S. I. GASWELL
9-016-058-04W4M	CS LINDBERGH 9-16	S. I. OILWELL
5-018-058-04W4M	CS LINDBERGH 5-18	S. I. OILWELL
07-021-058-04W4M	CS LINDBERGH 7-21	S. I. GASWELL
6-022-058-04W4M	FINA MURIEL LAKE 6-22	S. I. GASWELL
5A-026-058-04W4M	PCI LINDBERGH 5A-26	S. I. OILWELL
10-036-058-04W4M	KISSINGER FROG LAKE 10-36	GASWELL
14B-03-058-05W4M	MURPHY LINDBERGH 14B-3	OILWELL
3A-09-058-05W4M	MURPHY BOCO LINDBERGH 3A-9	S. I. GASWELL
11-011-058-05W4M	CANSALT LINDBERGH 11-11-58-5	GASWELL
7-016-058-05W4M	KISSINGER LINDBERGH 7-16	S. I. GASWELL
10-023-058-05W4M	AMOCO LINDBERGH 10-23	S. I. GASWELL
10-024-058-05W4M	AMOCO LINDBERGH 10-24	S. I. GASWELL
06-09-059-04W4M	CWWE ET AL MURIEL 6-9	ABD
011-014-059-04W4M	CWWE MURIELLK 11-14	ABD
010-016-059-04W4M	CWWE MURIEL 10-16	ABD WTR DISP WELL
010-017-059-04W4M	CWWE MURIELLK 10-17	ABD GASWELL
010-019-059-04W4M	CWWE ET AL MURIEL 10-19	ABD
07-020-059-04W4M	CWWE MURIELLK 7-20	ABD GASWELL
06-021-059-04W4M	WECO MURIEL 6-21	GASWELL
07-026-059-04W4M	KISSINGER AMOCO MURIEL 7-26	S.I. GASWELL
010-033-059-04W4M	KISSINGER AMOCO MURIEL 10-33	S.I. GASWELL

AREA 5

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
03C-04-061-02W4M	HUSKY BEAVERDAM 3C-4	S.I. GASWELL
012B-027-061-02W4M	HUSKY BEAVERDAM 12B-27	S.I. OILWELL
012A-031-061-02W4M	HUSKY KENT 12A-31	GASWELL
016-036-061-02W4M	SOBC BEAVERCK OBS EV 16-36	OBS. WELL
10D-08-062-02 W4M	HUSKY BEAVERDAM 10D-8	S.I. GASWELL

01/24/89

STATUS OF POTENTIAL MONITORING WELLS

AREA 6

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
6-020-061-04W4M	WECO FORT KENT 6-20	GAS SUSP
07-025-061-04W4M	KOCH FORT KENT 7-25	GAS FLOW
07-027-061-04W4M	KOCH FTKENT 7-27	GAS FLOW
6-034-061-04W4M	KOCH FTKENT 6-34	GAS FLOW
03-09-061-05W4M	SUNCOR ET AL FORT KENT 3-9	OBS SERVICE WELL
03-015-061-05W4M	SUNCOR ET AL FTKENT 3-15	UND SUSP
10-022-061-05W4M	SUNCOR AMOCO FTKENT 10-22	ABD HVY OIL OBS WELL
06-024-061-05W4M	SUNCOR AMOCO FTKENT 6-24	UND SUSP
06-025-061-05W4M	SUNCOR AMOCO FTKENT 6-25	UND SUSP
03-027-061-05W4M	SUNCOR ET AL FTKENT 3-27	UND SUSP
07-029-061-05W4M	SUNCOR AMOCO FTKENT 7-29	ABD

AREA 7

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
8-01-064-03W4M	ASHLAND ET AL COLD 8-1-64-3	UND SUSP
10-03-064-03W4M	MOBIL HILDA LK 10-3-64-3	UND SUSP
10-04-064-03W4M	MOBIL ETHEL LAKE 10-4	UND SUSP
6-010-064-03W4M	GPD YB ETHEL LAKE 6-10	GAS CAPPED
11-016-064-03W4M	GPD YB ETHEL LAKE 11-16	GAS CAPPED
10-027-064-03W4M	ESSO C1 MAY ETHELLK EX 10-27	CYCL
6-034-064-03W4M	ESSO 85 COLDLK OV 6-34	GAS CAPPED
11C-016-064-04W4M	HALB TUCKER 11C-16	UND SUSP
6B-021-064-04W4M	HUSKY TUCKER LAKE 6B-21	CR BIT SUSP
10D-021-064-04W4M	HUSKY TUCKER LAKE 10D-21	UND SUSP
11D-028-064-04W4M	HALB TUCKER LAKE 11D-28	UND SUSP
10B-029-064-04W4M	HUSKY EOR TUCKER LAKE EX 10B-29	CR BIT SUSP
10C-031-064-04W4M	HUSKY EOR TUCKER LAKE 10C-31	ABD
13C-032-064-04W4M	HUSKY TUCKER LAKE 13C-32	CYCL

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
013-011-065-02 W4M	GULF COLD LAKE 13-11	SHUT IN HVY O WELL
01-14-065-02 W4M	BVI A1 MARIE EX 1-14	HVY OILWELL
015-023-065-02 W4M	ESSO 86 COLDLK 15-23	S.I. GASWELL
014-033-065-02 W4M	ESSO 86 COLDLK 14-33	S.I. GASWELL

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
011-04-065-03 W4M	ESSO 74 LEMING 11-4	GASWELL
010-05-065-03 W4M	ESSO 77 ETHEL LAKE 10-5	GASWELL
03-07-065-03 W4M	ESSO CC18 LEMING ETHEL EX 3-7	HVY OILWELL
01-08-065-03 W4M	ESSO 014 LEMING ETHEL EX 1-8	HVY OILWELL
012-018-065-03 W4M	ESSO 87 C4-8 COLDLK 12-18	HVY OILWELL

03/30/89

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
07-09-065-05 W4M	BP PCI WOLF LAKE OV 7-9	P&A
011-014-065-05 W4M	ESSO 86 WOLFLK 11-14	ABD
02-016-065-05 W4M	TRIAD BP MARQUERITE LAKE 2-16-	SUSP-OIL
014-018-065-05 W4M	BP MARGUERITE LAKE 14-18	HVY OIL
06-022-065-05 W4M	BP MARGUERITE OV 6-22	ABD
04-024-065-05 W4M	ESSO 3-78 MARGUERITELK 4-24	GASWELL
06-027-065-05 W4M	BP LEMING 6-27	HVY OILWELL
010-028-065-05 W4M	BP PCI WOLF LAKE 10-28	ABD
014-029-065-05 W4M	BP PCI WOLF LAKE OV 14-29	P&A
07-031-065-05 W4M	BP LEMING 7-31	HVY OILWELL
09-032-65-05 W4M	BP PCI LEMING 9-32	S.I. GASWELL
011-034-065-05 W4M	BP PCI WOLF LAKE OV 11-34	P&A

09/01/89

AREA 8

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
011-06-064-06 W4M	MOBIL OBS WOLFLK EX 11-6	OBS WELL
06-08-064-06 W4M	MOBIL GARTH EX 6-8	OILWELL
06-011-064-06 W4M	MOBIL BARTH 6-11	S.I. GASWELL
014-017-064-06 W4M	MOBIL GARTH 14-17	GASWELL
010-019-064-06 W4M	MOBIL GARTH 10-19	S.I. GASWELL
06-023-064-06 W4M	MOBIL GARTH 6-23	S.I. GASWELL
07-030-064-06 W4M	MOBIL GARTH 7-30	S.I. GASWELL

01/24/89

AREA 9

STATUS OF POTENTIAL MONITORING WELLS

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
011-017-066-03W4M	ESSO 86 COLDLK 11-17	S.I. GASWELL
07-036-066-03W4M	ESO 85 COLDLK OV 7-36	S.I. HVY OILWELL

STATUS OF POTENTIAL MONITORING WELLS

AREA 10

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
016-03-066-05W4M	PB PCI WOLF LAKE 16-3	ABD
011-04-066-05W4M	BP LEMING 11-4	GAS CAPPED
011-07-066-05W4M	BP PCI 16K1 WOLF LAKE EX 11-07	CYCL
013-08-066-05W4M	BP 14-81 OB MARGLK 13-8	UND SUSP
06-010-066-05W4M	BP LEMING 6-10	GAS CAPPED
06-016-066-05W4M	BP LEMING 6-16	UND SUSP
05-017-066-05W4M	BP PCI 10E WOLF LK EX 5-17	CYCL
06-018-066-05W4M	BP MARGUERITE 6-18	UND SUSP
02-020-066-05W4M	BP 166 WOLF LAKE EX 2-20	OBS
07-026-066-05W4M	ESSO 85 WOLFLK OV 7-26	GAS CAPPED
010-031-066-05W4M	TRIAD MARGUERITE 10-31	GAS CAPPED
06-033-066-05W4M	BP PCI WOLF LAKE 6-33	GAS CAPPED
06-034-066-05W4M	BP PCI WORF LAKE 6-34	UND SUSP
010-036-066-05W4M	ESSO 85 WOLFLK 10-36	GAS CAPPED

STATUS OF POTENTIAL MONITORING WELLS

AREA 11

WELL LEGAL LOCATION	NAME OF WELL	WELL STATUS
09-05-067-04W4M	DOME ET AL 9CK PRIMROSE EX 9-5	OILWELL
010-07-067-04W4M	DOME AEC MARGUERITE LAKE 10-7	S.I. OILWELL
09-09-067-04W4M	DOME AEC FISHERCK 9-9	S.I. GASWELL
010-010-067-04W4M	DOME AEC MOORE 10-10	S.I. GASWELL
02-012-067-04W4M	DOME AEC BURNT LAKE 2-12	S.I. GASWELL
07-022-067-04W4M	DOME AEC FISHERCK 7-22	S.I. GASWELL
011-024-067-04W4M	DOME AEC BURNT LAKE 11-24	S.I. GASWELL
010-026-067-04W4M	DOME AEC BURNT LAKE 10-26	GASWELL
011-028-067-04W4M	DOME AEC MARGUERITE 11-28	GASWELL
07-033-067-04W4M	DOME AEC FISHERCK 7-33	S.I. GASWELL

APPENDIX E

SAMPLE DATA FILE FROM ERCB COMPUTER

```
DDN0532-01         ENERGY RESOURCES CONSERVATION BOARD          01 MAY 1989
                    DATA DISSEMINATION - GENERAL QUERY

                         DATA GROUP SELECTION MENU
                        SELECT DATA GROUP(S)  Y=YES

  ALL. . . . . . . . . . . . . . .: y     PLUG BACK/ABANDONMENT. . . . . . .:
  BASIC DRILLHOLE. . . . . . . .:         CORES CUT. . . . . . . . . . . . .:
  LICENSING/INCENTIVES . . . . .:         CORE HEADER. . . . . . . . . . . .:
  AGENT/LICENSEE/MINERAL RIGHT:           CORE HEADER & LINE DETAIL. . . . .:
  GEOLOGICAL TOPS & MARKERS. .:           DST/WIRELINE/C.R. RUN. . . . . . .:
  DRILLING OCCURRENCE DATA . .:           DST/WIRELINE/C.R. SAMPLER DETAIL:
  DRILLED HOLE DATA. . . . . . .:         LOGS RUN . . . . . . . . . . . . .:
  CASING & CEMENTING DATA. . .:           WELL STATUS HISTORY. . . . . . . .:
  PERFORATIONS/TREATMENTS. . .:
  INITIAL PRODUCTION-PERF/FLOW:

  IF DATA BY INTERVAL IS REQUIRED, ENTER INTERVAL:      TO      METRES
  (INTERVAL MUST BE SPECIFIED TO NEAREST METRE)


** PLEASE PRESS ENTER WHEN SELECTION IS COMPLETE **
```

```
DDN0604-01           ENERGY RESOURCES CONSERVATION BOARD             01 MAY 1989
                      DATA DISSEMINATION - GENERAL QUERY

WELL ID      : 00/16-16-055-06W4/0        AMOCO 02 LINDBERGH 16-16-55-6
LICENSE NO. :  0110841                    LICENSEE: 00602 AMOCO CAN PET
LICENSE DATE: 20 NOV 1984                 AGENT    :
CONTRACTOR CODE: 0X68                     RIG NO   : 0033
-------------------------- BASIC DRILLHOLE DATA -------------------------------
FIELD        :  558 LINDBERGH                          -------- DEPTHS (M) ---------
POOL         :                                         TOTAL:   669.00 SS:      12.70
OS AREA      : A010 COLD LAKE                          PB   :           SS:
DEPOSIT      :  306202 WABISKAW-MCMURRAY B             TVD  :           SS:
LAHEE CLASS: 00 DEVELOPMENT                            CONF : (NC)
WELL STATUS: 17      11      00      00
             CR-BIT PUMP                                    ------- DATES --------
STATUS DATE:  2 JAN 1985                                    SPUD      : 29 NOV 1984
                                                            FIN-DRILL:  1 DEC 1984
--CO-OR-- ---LONGITUDE---- ---LATITUDE--- --ELEV (M)---   RIG REL. :  3 DEC 1984
S   319.9 ACT:  110.824326 ACT: 53.755667 GRD:   677.60   ON PROD. :  2 JAN 1985
W   187.6 THE:  110.820672 THE: 53.756876 KB :   681.70   ON INJ.  :
                                          CF :
BOTTOM HOLE CO-ORDINATES = SURFACE CO-ORDINATES
```

```
DDN0606-01            ENERGY RESOURCES CONSERVATION BOARD             01 MAY 1989
                       DATA DISSEMINATION - GENERAL QUERY

  WELL ID  : 00/16-16-055-06W4/0       AMOCO 02 LINDBERGH 16-16-55-6
  LICENCE #:  0110841                  LICENCE DATE: 20 NOV 1984
  ---------------------------- LICENCE DATA ----------------------------------
  LICENSED UNDER SECTION   2.020  OF THE OIL & GAS CONSERVATION ACT
  PURPOSE:
    OBTAIN PRODUCTION OF CRUDE BITUMEN FROM THE CUMMINGS


  SURFACE LOC : 16-16-055-06W4 M     GROUND ELEVATION:  677.6   M
  CO-ORDINATES:  319.9  S     187.6  W
  PROJECTED TD:   671 M      PROJ.TERM.FORM.: 3280 MCMURRAY FM
  CONF. TD    :              CONF.TERM.FORM.:
  FIELD          558 LINDBERGH
  AREA OFFICE :  5 BONNYVILLE                      SCHEME APPROVAL #:

  ----------------------------INCENTIVES DATA ----------------------------
  LAHEE CLASS ---CONF STATUS---- CERTIFICATE NO.  ---DATE----     COST AREA
  00 DEV      NON-CONFIDENTIAL
```

```
DDN0614-01          ENERGY RESOURCES CONSERVATION BOARD          01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

 WELL ID  : 00/16-16-055-06W4/0          AMOCO 02 LINDBERGH 16-16-55-6
 LICENSE #:  0110841                     LICENSE DATE: 20 NOV 1984

 ----------------------- APPLICANT/AGENT/CONTRACTOR -----------------------
   LICENSEE: 00602 AMOCO CANADA PETROLEUM COMPANY LTD.
                   600-10040-104 ST
                   EDMONTON            ALTA            T5J0Z2

      AGENT:


 DRILLING
 CONTRACTOR: 0X680 WESTBURNE DRILLING (CANADA) LTD
 RIG NUMBER: 0033

   ------------------- SURFACE/MINERAL RIGHTS OWNERSHIP -----------------------
   SURFACE RIGHTS OWNER: 2 FREEHOLD            HEAD LESSOR: 1 CROWN
         AGREEMENT TYPE:  71 BITUMINOUS SANDS LEASES
           AGREEMENT NO: 7183110254            EXPIRY DATE:
```

```
DDN0618-01          ENERGY RESOURCES CONSERVATION BOARD          01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0               AMOCO 02 LINDBERGH 16-16-55-6
LICENCE #:  0110841                          KB:   681.70 M    TD:   669.00 M
FIN-DRILL-DATE: 01 DEC 1984                  GEO-REVISED-DATE: 26 AUG 1986

                       GEOLOGICAL TOPS & MARKERS - LOG
                                 DEPTH   SUB-SEA
----------FORMATION---------- --(M)--- ---(M)--- ----QUALITY----  -DESCRIPTION-
1860 SECOND WHITE SPECKLED SH  382.00    299.70 LOGS, GOOD        TOP
2060 BASE FISH SCALES ZONE     418.00    263.70 LOGS, GOOD        TOP
2180 VIKING SANDSTONE          464.00    217.70 LOGS, GOOD        TOP
2620 GRAND RAPIDS FM           506.30    175.40 LOGS, GOOD        TOP
2760 SPARKY MBR                546.30    135.40 LOGS, GOOD        TOP
2800 CLEARWATER FM             593.50     88.20 LOGS, GOOD        TOP
3020 CUMMINGS MBR              629.00     52.70 LOGS, GOOD        TOP
3280 MCMURRAY FM               648.70     33.00 LOGS, GOOD        TOP
9999 TOTAL DEPTH               669.60     12.10
```

```
DDN0802-01          ENERGY RESOURCES CONSERVATION BOARD            01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0              AMOCO 02 LINDBERGH 16-16-55-6
LICENCE #:  0110841                         KB:    681.70 M  TD:    669.00 M

                          DRILLING OCCURRENCE DATA

OCCURRENCE TYPE . . .:
OPERATION IN PROGRESS:
OCCURRENCE DATE . . .:
OCCURRENCE DEPTH (M).:
MUD DENSITY (KG/M3) .:
VISCOSITY (S/L) . . .:
CONTROL DATE. . . . .:
CONTROL DEPTH (M) . .:
MUD DENSITY  (KG/M3).:
VISCOSITY (S/L) . . .:
WATER FLOW SEVERITY .:
WATER FLOW RATE(M3/D):
LOST CIRC. SEVERITY .:
LOST CIRC. LOSS (M3).:

NO DRILLING OCCURRENCE AVAILABLE, PLEASE PRESS ENTER TO CONTINUE
```

```
DDN0804-01          ENERGY RESOURCES CONSERVATION BOARD            01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0             AMOCO 02 LINDBERGH 16-16-55-6
LICENSE #:  0110841                        KB:    681.70 M TD:    669.00 M

---DRILLED HOLE DATA----   -----------DIRECTIONALLY DRILLED DATA---------------
NO. SIZE(MM)  DEPTH(M)     NO.    DATE      DEPTH(M)        DESCRIPTION
 1    374.6     106.00
 2    250.8     669.00
```

```
DDN0806-01          ENERGY RESOURCES CONSERVATION BOARD             01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0             AMOCO 02 LINDBERGH 16-16-55-6
LICENSE #:  0110841                        KB:   681.70 M  TD:   669.00 M
                            CASING AND CEMENTING
                    -----  1 ----  -----  2 ----
 OBSERVATION DATE.: 30 NOV 1984     2 DEC 1984
 CASING TYPE . . .: SURFACE        PRODUCTION
 CASING SIZE(MM) .: 273.0          177.8
 SHOE SET (M). . .:   106.00         669.00
 LINER TOP (M) . .:
 CASING DEN(KG/M3):  60.3           34.2
 GRADE(STEEL PROC):   K              L
 GRADE (STRENGTH).:  55             80
 COLLAR TYPE . . .:  ST&C
 MIX STRING. . . .: NO             NO
                    ------ 1 ----- ------ 1 -----
 CEMENT STAGE NO .:
 CEMENT AMOUNT . .:   16.0 TONNES    23.5 M3
 CEMENT TYPE . . .: CLASS G NEAT   CLASS G NEAT
 RE-CEMENT . . . .: NO             NO
```

```
DDN0810-01          ENERGY RESOURCES CONSERVATION BOARD           01 MAY 1989
                      DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0              AMOCO 02 LINDBERGH 16-16-55-6
LICENCE #:  0110841                         KB:   681.70 M  TD:   669.00 M
                                            DEEPEST CASING DEPTH:   669.00 M

--------------- PERFORATIONS AND TREATMENTS -----------  ----- PACKER DATA -----
                                                 SHOTS/
NO.  ---DATE----   --TYPE--- ---INTERVAL(M)----- METER  NO ---DATE---- DEPTH(M)
 1   31 DEC 1984    2 JET      629.50 -   632.50   13
 2   31 DEC 1984    2 JET      637.00 -   640.00   13
 3   31 DEC 1984    2 JET      641.50 -   643.50   13
```

```
DDN0822-01          ENERGY RESOURCES CONSERVATION BOARD           01 MAY 1989
                      DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0            AMOCO 02 LINDBERGH 16-16-55-6
LICENCE #:  0110841                       KB:  681.70 M   TD:  669.00 M

                  INITIAL PRODUCTION - PERFORATION/FLOW TESTS
                                                                 GAS RATE
NO.  ---DATE----  ---INTERVAL(M)---  --TEST TYPE--   FLOW/(HR)  (1000 M3/D)


   ----------------------FLUID-------------------          --PRESSURE(KPA)--
         TYPE        RECOVERED(M3)    RATE(M3/D)             FLOW      STATIC

                 -----------------ADDITIONAL DATA----------------



NO PERF/FLOW TEST DATA AVAILABLE, PLEASE PRESS ENTER TO CONTINUE.
```

```
DDN0826-01          ENERGY RESOURCES CONSERVATION BOARD          01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0          AMOCO 02 LINDBERGH 16-16-55-6
LICENCE #:  0110841                     KB:  681.70 M  TD:  669.00 M

                          PLUG BACK AND ABANDONMENT


OBSERVATION DATE:
OBSERVATION DESC:
PLUG INTERVAL(M):
CEMENT QUANTITY.:
TOP FOUND(M) . .:


SURFACE ABAND. DATE :
ABANDONMENT DESCRIP.:


NO PLUG BACK & ABANDONMENT AVAILABLE, PLEASE PRESS ENTER TO CONTINUE
```

```
DDN0814-01          ENERGY RESOURCES CONSERVATION BOARD            01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0             AMOCO 02 LINDBERGH 16-16-55-6
LICENCE #:  0110841                        KB:   681.70 M  TD:   669.00 M

                                 CORES CUT

       CORE CUT         CORED            CORING    CORE CUT   CORE    CORE ANAL
 NO   ---DATE---- ----INTERVAL (M)---  -FLUID--   --TYPE--  RECOV(M) RECEIVED











NO CORES CUT AVAILABLE, PLEASE PRESS ENTER TO CONTINUE
```

```
DDN0702-01           ENERGY RESOURCES CONSERVATION BOARD            01 MAY 1989
                      DATA DISSEMINATION - GENERAL QUERY

    WELL ID  : 00/16-16-055-06W4/0    AMOCO 02 LINDBERGH 16-16-55-6
    LICENSE #:  0110841               CA #:             REPORT TYPE: 1 REGULAR
                                                                     2 SIEVE
                         CORE ANALYSIS - HEADER DATA

---------------------------- GENERAL INFORMATION -----------------------------
LAB. NAME  :                                    ANALYSIS DATE:
LAB. FILE #:                                    ANALYST NAME :

------------------------------ CORE INFORMATION -------------------------------
    CORE CUT DIAMETER:
       CORE CUT FLUID:
        CORE CUT TYPE:
        CORE HANDLING:
    GAMMA CORRELATION:    (Y/N)

----------------------------- SAMPLE INFORMATION-------------------------------
SAMPLE SHAPE:                SAMPLE DIAMETER:            SAMPLE LENGTH:

NO CORE ANALYSIS DATA FOR THIS WELL, PLEASE PRESS ENTER TO CONTINUE
```

```
DDN0818-01          ENERGY RESOURCES CONSERVATION BOARD          01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0             AMOCO 02 LINDBERGH 16-16-55-6
LICENCE #:  0110841                        KB:    681.70 M  TD:    669.00 M

                              DST & WIRELINE TESTS RUN
TEST SUB
 NO  NO  --------TEST TYPE-------- ---DATE----  ---MISRUN-- -TEST INTERVAL (M)-








NO DST RUNS AVAILABLE, PLEASE PRESS ENTER TO CONTINUE
```

```
 DDNO722-01          ENERGY RESOURCES CONSERVATION BOARD             01 MAY 1989
                      DATA DISSEMINATION - GENERAL QUERY

 WELL ID  : 00/16-16-055-06W4/0      AMOCO 02 LINDBERGH 16-16-55-6
 LICENCE #:  0110841                 FIN-DRILL-DATE: 01 DEC 1984  TD:    669.00 M

  TESTING COMPANY:                                    STATIC PRESS:
        TEST DATE:                                  FIN-FLOW-PRESS:
        TEST TYPE:                 NO:             VALVE OPEN TIME:
     TEST QUALITY:                                 PIPE INTER. DIA:
    TEST INTERVAL:                                    CUSHION TYPE:
   RECORDER DEPTH:                                  CUSHION LENGTH:
   --------------------    --TIME-   ----MAX. FLOW----    ----FINAL FLOW----
   TO SURFACE     GAS
    READINGS      OIL
                  WATER

                             ----- FLUID TYPE------    MEASUREMENT
             RECOVERIES


NO DST DATA AVAILABLE, PLEASE PRESS ENTER TO CONTINUE
```

```
DDN0726-01          ENERGY RESOURCES CONSERVATION BOARD          01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID  : 00/16-16-055-06W4/0                   FIN-DRILL-DATE: 01 DEC 1984
           AMOCO 02 LINDBERGH 16-16-55-6         KB:    681.70 M
LICENCE #:  0110841                              CORE ANALYSED: NO

                                LOG DATA
RUN     RUN        CO.                                       INTERVAL (M)
NO.   ---DATE----  CODE ------------LOG TYPE------------    --TOP--   --BASE--
01     2 DEC 1984  HIST  0625  DUAL SPACED NEUTRON           90.00 -   668.90
01     2 DEC 1984  HIST  0704  DUAL INDUCTION GUARD LOG      90.00 -   669.00
01    16 DEC 1984  HIST  1703  GAMMA RAY CORR                20.00 -   650.00
02    31 DEC 1984  HIST  1703  GAMMA RAY CORR               575.00 -   654.50
```

```
DDN0838-01          ENERGY RESOURCES CONSERVATION BOARD               01 MAY 1989
                     DATA DISSEMINATION - GENERAL QUERY

WELL ID     : 00/16-16-055-06W4/0             AMOCO 02 LINDBERGH 16-16-55-6
LICENSE NO.:  0110841                         KB:   681.70 M   TD:   669.00 M
CUR. STATUS: 17      11      00      00       CURRENT STATUS DATE:  2 JAN 1985
             CR-BIT PUMP
                          HISTORICAL WELL STATUS

    ---DATE----   -----CODE-----   --------------STATUS--------------








NO HISTORICAL WELL STATUS, PRESS ENTER TO CONTINUE
```